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LONG RANGE RADAR COMPATIBILITY ANALYSIS IN THE 1300-1350 MHZ FR--ETC(U)

JAN 76 D GRIGG, B PIEPER, D LOVE, M KELLY F19628-76-C-0017

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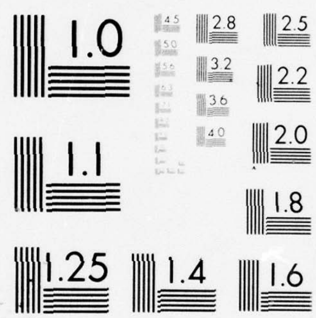

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FAA-RD-76-200

(12)

LONG RANGE RADAR COMPATIBILITY ANALYSIS IN THE 1300-1350 MHz FREQUENCY BAND

IIT Research Institute
Under Contract to
DEPARTMENT OF DEFENSE
Electromagnetic Compatibility Analysis Center
Annapolis, Maryland 21402

January 1976

FINAL REPORT

Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, DC 20591

FAA-RD-76-200

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FAA-RD-76-200	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle LONG RANGE RADAR COMPATIBILITY ANALYSIS IN THE 1300-1350 MHz FREQUENCY BAND.		5. Report Date January 1976 6. Performing Organization Code
7. Author(s) David Grigg, Brian Pieper, Dennis Love, and Michael Kelly of IIT Research Institute		8. Performing Organization Report No. ECAC-PR-75-074
9. Performing Organization Name and Address DoD Electromagnetic Compatibility Analysis Center North Severn Annapolis, Maryland 21402		10. Work Unit No. Project 2/3-061-00 11. Contract or Grant No. IAA; DOT-FA70WAI-175 Task-21 13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, DC, 20591		FINAL rept. 14. Sponsoring Agency Code

15. Supplementary Notes

Performed for Spectrum Management Staff, FAA.

16. Abstract

The feasibility of introducing new dual-frequency-diversity radars (ARSR-3), which are designed to operate in the 1250-1350 MHz frequency band, into the present environment was investigated. The electromagnetic environment surrounding four sites was analyzed to determine the electromagnetic compatibility both before and after introduction of the ARSR-3 at each site. Frequency assignment techniques and other operational procedures necessary to maintain current levels of compatibility are identified.

(15) F19628-76-C-0017, DOT-FA70WAI-175

(18) ECAC, FAA-RD

(19) PR-75-074, 76-200

175 300

17. Key Words AIR ROUTE SURVEILLANCE RADARS ELECTROMAGNETIC COMPATIBILITY DUAL-FREQUENCY-DIVERSITY RADARS	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	181	

Form DOT F 1700.7 (8-69)

PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military department and other DoD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Office of the Secretary of Defense, Director of Telecommunications and Command and Control Systems and the Chairman, Joints Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WAI-175, as part of AF Project 649E under Contract F-19628-76-C-0017, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the United States of America Standards Institute.

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DDC	Buff Section	☐
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METRIC CONVERSION FACTORS

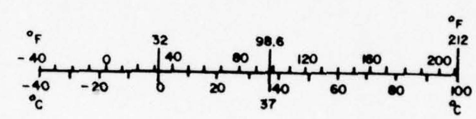
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) has developed a new generation Air Route Surveillance radar (ARSR-3) to modernize and expand its network of long-range radars (LRR). These radars function as part of the system providing air traffic control separation service to all aircraft operating on an instrument flight rule (IFR) flight plan within enroute controlled airspace. In 1976, FAA was proceeding towards the installation of the ARSR-3 at various sites.

FAA has requested that the DoD Electromagnetic Compatibility Analysis Center (ECAC) determine means by which the present level of electromagnetic compatibility (EMC) in the 1300-1350 MHz frequency band could be maintained with the introduction of the ARSR-3, a dual-frequency-diversity radar, into the environment.

The present usage of the 1215-1350 MHz frequency portion of L-Band was determined. Based on this data, FAA LRR sites that are situated in dense L-Band radar environments were selected for analysis.

Using interference criteria related to the number of interference pulses displayed per antenna scan on the radar presentation scope, the current level of environmental EMC with the FAA LRR was compared with the level resulting from the ARSR-3 replacing the present LRR.

The results of the analysis showed that an ARSR-3 frequency assignment could be made with minimum reassignment for other environmental radars in the 1250-1350 MHz frequency band.

EXECUTIVE SUMMARY (Continued)

Appropriate frequency assignments were achieved such that: (1) the military radars will maintain no worse than a scope condition 1 display presentation, (2) interference pulse counts at FAA radars not scheduled for conversion will remain approximately constant, and (3) interference pulse counts at the ARSR-3 will not be more than twice the number occurring at the radar being replaced.

Further, the interference pulse counts for all types of FAA radars can be reduced considerably through appropriate use of available special processing circuitry (integrators or digitizing equipment).

TABLE OF CONTENTS

Subsection Page

SECTION 1

INTRODUCTION

SECTION 2

ANALYSIS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

Subsection Page

SECTION 3

RESULTS AND CONCLUSIONS

LIST OF ILLUSTRATIONS

Figure

TABLE OF CONTENTS (Continued)

LIST OF TABLES

TABLE OF CONTENTS (Continued)

LIST OF TABLES (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES (Continued)

LIST OF APPENDIXES

SECTION 1

INTRODUCTION

BACKGROUND

The Federal Aviation Administration (FAA) has developed a new generation Air Route Surveillance radar (ARSR-3). The FAA plans to install at least 21 of the new L-Band radars in order to modernize and expand its network of long-range radars (LRR). Another ARSR-3 radar is to be installed at the FAA Academy in Oklahoma City for training. Unlike the present LRRs, the ARSR-3 employs dual-frequency-diversity operation to provide enhanced target detection capability and increased system reliability. The Spectrum Management Staff of the FAA has requested that the Electromagnetic Compatibility Analysis Center (ECAC) determine means by which dual-frequency-diversity operation can be introduced into the L-Band frequency range.

In the United States, radar usage in L-Band is primarily in the 1215-1400 MHz frequency range. The frequency spectrum from 1300 to 1350 MHz is allocated to Aeronautical Radionavigation (AR) on a primary basis and is the prime candidate in deploying the ARSRs. Due to the requirement for 30-MHz separation between ARSR-3 frequencies, the 1215 to 1300 MHz band is also of interest. This band is allocated to Radiolocation on a primary basis, but joint use of this band by the FAA and Department of Defense is allowed and unilaterial FAA operation of Air Route Surveillance radars in this band is allowed under certain conditions.

OBJECTIVES

The objectives of the analysis were to:

1. Determine current use of the 1215-1350 MHz frequency band and to identify deployment congestion of radars within the band.

2. Determine the present degree of electromagnetic compatibility in the 1300 to 1350 MHz band.

3. Determine the impact of operating the new dual-frequency-diversity radars (eg. ARSR-3) in the 1300-1350 MHz frequency band.

4. Consider optional configurations of radar parameters and adjacent frequency band usage if operation of the new dual-frequency-diversity radar in the 1300 to 1350 MHz frequency band should pose EMC problems.

APPROACH

A general band study was made to determine the present use of the 1215 to 1350 MHz portion of L-Band. Equipment type, function and EMC characteristics were determined. Pertinent regulations and rules covering the use of the band were identified. The general band study is presented in APPENDIX A. The 1350-1400 MHz part of L-Band is outside the tuning range of the ARSR-3. Therefore, this part of the spectrum was not considered in the band study.

The general band study was used to select representative sites for detailed analysis. The following sites were selected: Bedford, VA, Suitland, MD, Atlanta, GA, San Pedro Hill near Los Angeles, CA. These are representative of radar sites located in a dense radar

environment. The basis of selection was radar equipment density numbers developed for all of the FAA long range radar sites. The equipment density study is presented in APPENDIX B. One other site, Trevose, PA, was also analyzed at FAA's request. This site was of interest because it has a dual-frequency-diversity radar, a one-of-a-kind ARSR-60.

Two equipment system configurations were considered. One configuration uses a broadband microwave transmission system to transmit information between the remote ARSR and the Air Route Traffic Control Center (ARTCC). Either normal video or integrated normal video can be transmitted with provision for using MTI in a gated range. The other configuration uses a narrowband transmission system to transmit detected target information to the center. The detection logic is part of the digitizer equipment that is located at the radar site. Both the integrator and the digitizer were analyzed and their processing considered in the interference analysis.

The ARSR-3 has two unique EMC characteristics, a channel separation requirement and summation of interference from the two channels. The ARSR-3 requires two channels which are at least 30 MHz apart. Since both channels are used simultaneously, the interference in each channel was predicted and then summed together to determine the total interference situation at the radar. In situations where interference was predicted for a frequency separation of 30 MHz between channels, the separation was reduced to 20 MHz and the analysis repeated to determine if a reduced interference level could be realized.

Two interference criteria were applied in the ARSR analysis. One stringent interference criterion was designated by FAA and

previously used in an ECAC analysis of S-Band.[1] The other less stringent criterion was also used in the S-Band report. Several areas were investigated for background material before these criteria were selected. One area was the examination of interference reports from band users. Another area was visits to several radar sites and ARTCC's to interview FAA personnel and observe typical interference levels.

The selected sites were then analyzed to determine the existing compatibility in the 1300 to 1350 MHz band. The first step in the site analysis task was the compilation of detailed environmental data for the areas selected. The equipments and their EMC characteristics were determined from ECAC files. The specific operating frequencies were obtained through contact with the user community. The analysis consisted of calculating the interference level for each equipment in the environment. The interference measure was the number of visible pulses of interference per scan. Two site trips were made to verify the analysis approach, the environment, and frequency reporting accuracy.

The next step was to introduce the dual-frequency-diversity radars into the environment and predict their impact on electromagnetic compatibility. Where required, several frequency assignment philosophies were used with the new equipment. A frequency assignment of the ARSR-3 was attempted in the 1300-1350 MHz range without reassigning existing equipments. If this was not successfull, existing equipments located nearby were also reassigned. If this procedure failed to yield a compatible environment, the frequency band from 1250-1350 MHz was used for frequency assignment.

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[1]Maiuzzo, M. A., *Analysis of Factors Affecting Electromagnetic Compatibility In The 2700 to 2900 MHz Band*, FAA-RD-71-91, FAA, Washington, DC, July 1972.

The frequency assignment effectiveness was measured by calculating the interference pulse count for each resulting frequency assignment. These pulse counts for the new radars were evaluated on a relative basis (better or worse) by comparison with the pulse count for the existing radars and on an absolute basis (good or bad) by comparison with the interference criteria.

SECTION 2

ANALYSIS

EQUIPMENT CONFIGURATION

System Description

Air traffic enroute control primarily provides service to all aircraft on an instrument flight rule (IFR) flight plan operating within enroute controlled airspace. These services are provided from a facility known as an Air Route Traffic Control Center (ARTCC). At present there are 20 ARTCC centers in the contiguous United States. The center boundaries are shown on the map in FIGURE 1. Other major facilities used by controllers providing the enroute control service are: long-range radars (LRR), radar microwave links (RML), remote center air/ground facilities (RCAG), computer systems, and an internal communications system.

The present long-range radar network consists of 92 radar systems located in the contiguous United States. This network provides continuous radar surveillance of approximately 90 percent of the airspace at flight level 240 and above, which includes about 60 percent of all IFR air traffic. The majority of the 92 systems use ARSR-1, ARSR-2, FPS-7, or FPS-60 radars. FAA plans call for the replacement of all earlier type systems with new state-of-the-art ARSR-3's.[2] The ARSR-3 will eliminate many of the present deficiencies, reduce maintenance, and increase reliability through the use of solid-state and integrated circuit technology. An initial step of the modernization plan calls for

[2] *National Aviation System Plan, Fiscal Years 1976-1985*, Department of Transportation, FAA, Washington, DC, March 1975.

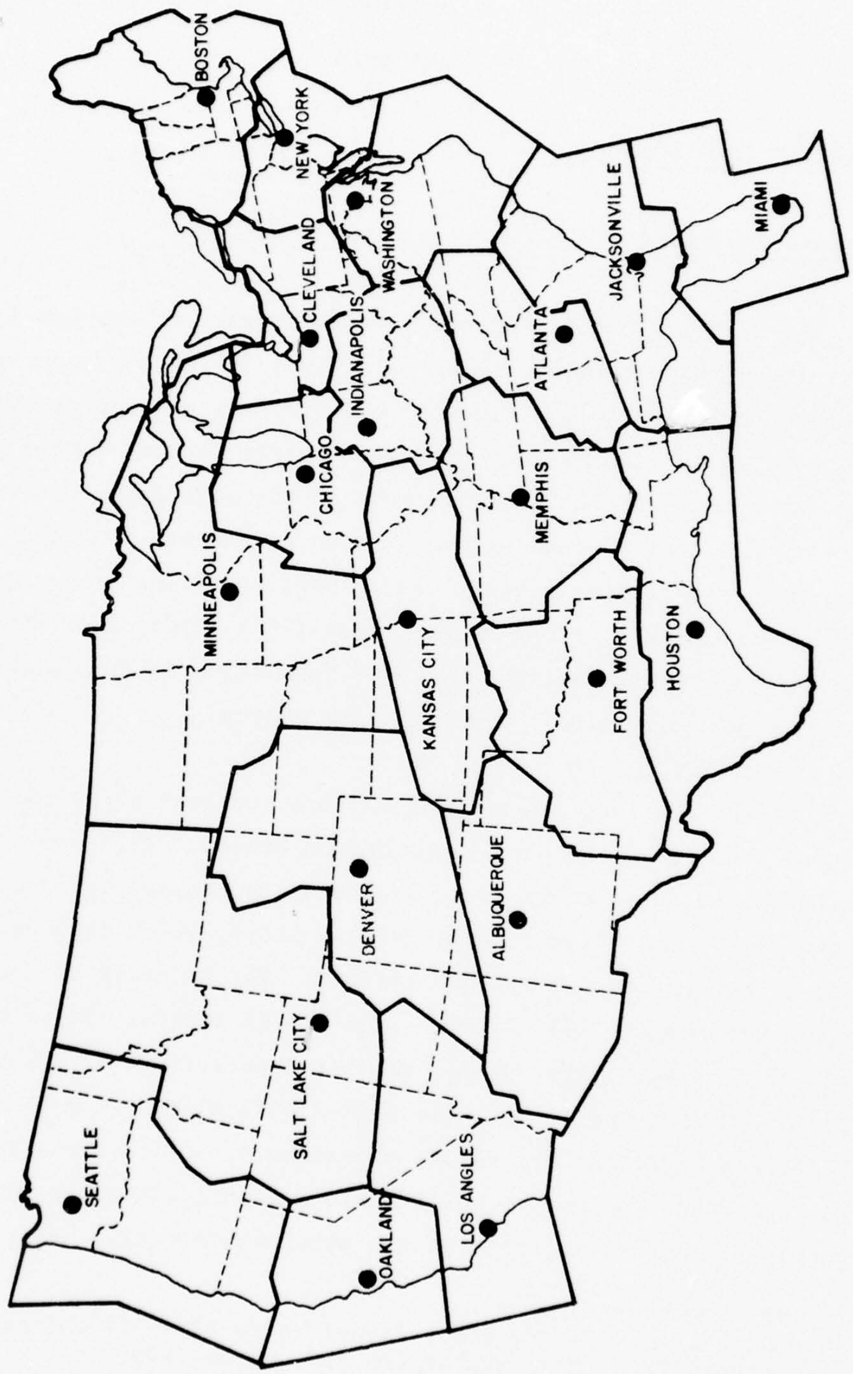


FIGURE 1. AIR ROUTE TRAFFIC CONTROL CENTERS.

the installation of 22 long-range radars at the proposed locations as provided by the FAA and listed in TABLE 1.

TABLE 1

FAA PROPOSED LOCATIONS - ARSR-3 LONG RANGE RADAR

1.	New York, NY[a,c]	13.	Lakeside, MT[a,c]
2.	Chicago, IL[a]	14.	Newport, MS[a]
3.	Washington, DC (Suitland)[a,c]	15.	Finley, ND[b,c]
4.	Waterloo, IA[a]	16.	Lake Havasu, AZ[b,c]
5.	Ivor, VA[a,c]	17.	Finland, MN[b,c]
6.	Fire Island, AK (replacement)[a]	18.	DuBois, PA[b,c]
7.	Empire, MI[a,c]	19.	Anson, TX[b]
8.	MacDill, FL[a,c]	20.	Cross City, FL[b,c]
9.	Mt. Laguna, CA[a,c]	21.	Condon, OR[b]
10.	Mt. Kaala, HA[a]	22.	FAA Academy, Oklahoma City, OK[b,d]
11.	Aiken, SC[a]		
12.	Kirksville, MO[a]		

Summary

1.	Total Fixed Installations	22
	a. Replacements	14
	b. New Installations	8
2.	Mobile Enroute Radar Facility (MERF)	4
3.	Joint Surveillance Systems	9

[a]Replacements
[b]New Installations
[c]Joint Surveillance Systems
[d]Training Equipment

A basic system block diagram of a long range radar and remote display is shown in FIGURE 2. The display shows two possible configurations, one for transmitting wideband video and the other for transmitting narrowband or digitized video. For the top configuration (wideband video), there is an option of transmitting normal video or integrated video. For the bottom configuration (narrowband video), only one option is shown and this includes the detection processing of the digitizer. These modes of operation, normal video, integrated normal, and digital are the three modes considered in this report. The pulse count is based on normal video while the signal processing is analyzed in APPENDIX E and F and the effects presented in a summary section. These are the dominant modes used. It is recognized that several other types of processing, MTI, STC, FTC, etc., are available that were not considered.

The ARSR-3 includes a new technique to minimize clutter and spurious target echoes, known as angels. This is the use of dual receiving horns which provide two partially overlapping beams for receiving target echoes. Because clutter and spurious echoes are most often received at low-elevation angles and close-in ranges, the signal from the upper receive-beam is used for closer range surveillance and the system automatically makes increased use of the signal from the lower receive-beam at longer ranges. Transmission occurs only on the lower beam.

Dual-Frequency-Diversity Radar

The ARSR-3 is two radars in a single system, completely redundant except for the antenna. The two transmitters operate at different frequencies within L-Band to provide frequency-diversity operation that enhances target detectability. Each can be operated

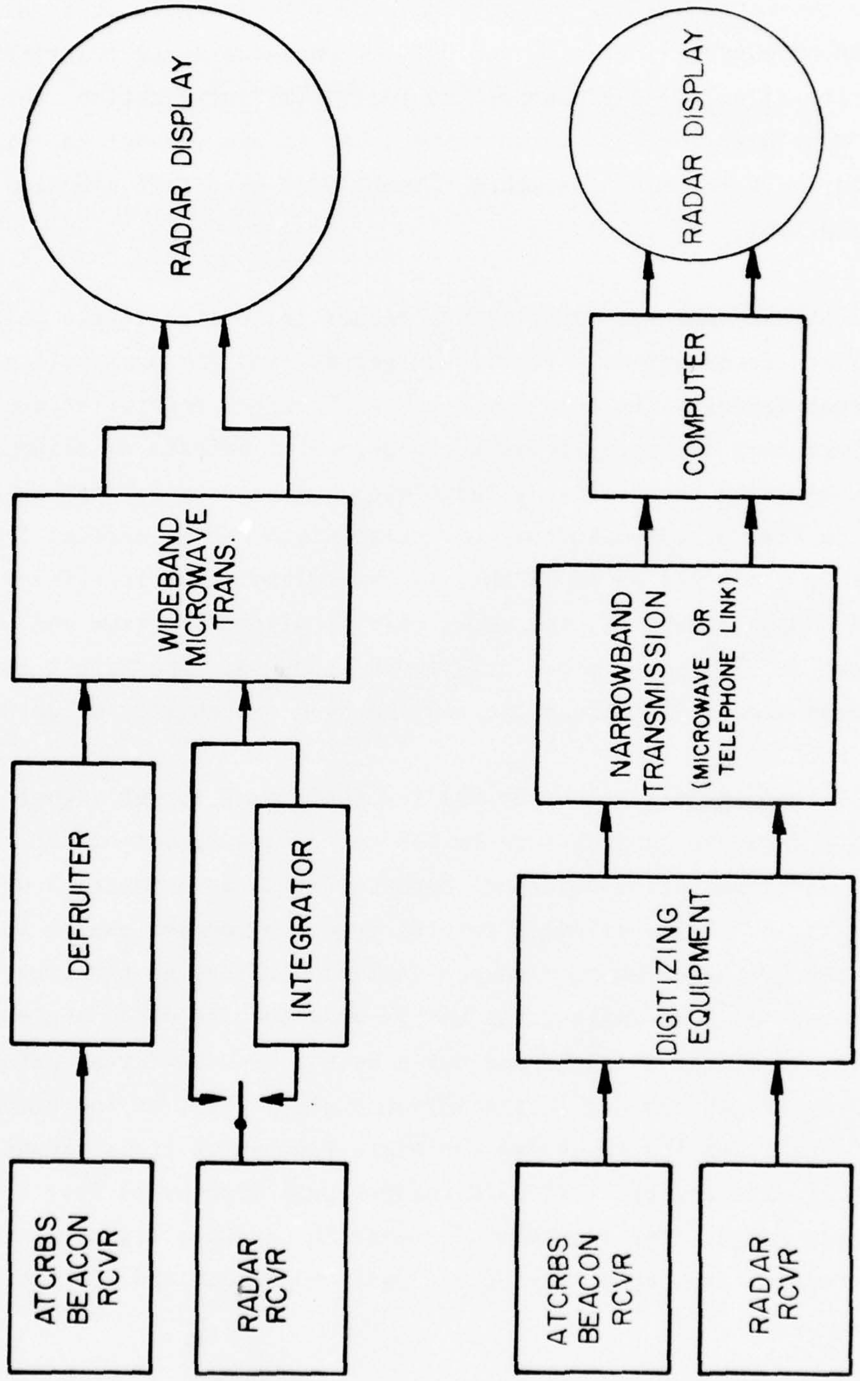


FIGURE 2. SYSTEM BLOCK DIAGRAM.

with a choice of horizontal, vertical, or circular polarization. However, frequency diversity can only be operated using polarization diversity (i.e., if one channel has horizontal polarization, the other must have vertical polarization, and if one channel has right circular polarization, the other channel must have left circular polarization).

Conventional air surveillance radars transmit a single pulse at a fixed frequency each repetition period, and the probability of target detection is degraded because of target scintillation. Dual-frequency diversity reduces the degrading effects of scintillation by using the following techniques. A pair of pulses, separated in time by approximately one pulse width and in carrier frequency by a desired Δf of 30 MHz, is transmitted each repetition period. Upon reception, the pulse-pair is aligned in time and summed as shown in the system block diagram in FIGURE 3. The result is an increased signal-to-noise ratio and improved probability of detection.

Target scintillation, or the fluctuation of target signal strength from one antenna scan to the next, is a result of the variations in target backscattering characteristics as a function of aspect angle. This variation results from the complex manner in which energy is reflected from the various surfaces of the aircraft structure. At some angles, the energy adds and, at other angles, cancels, resulting in peaks and nulls in the backscattering pattern with only slight changes in the aspect angle. Thus, as the aircraft progresses along its track and the angle from which it is viewed by the radar changes, the reflected radar signal fluctuates over a considerable range. The resultant decrease in average signal-to-noise ratio reduces the capability of the radar to detect the aircraft target.

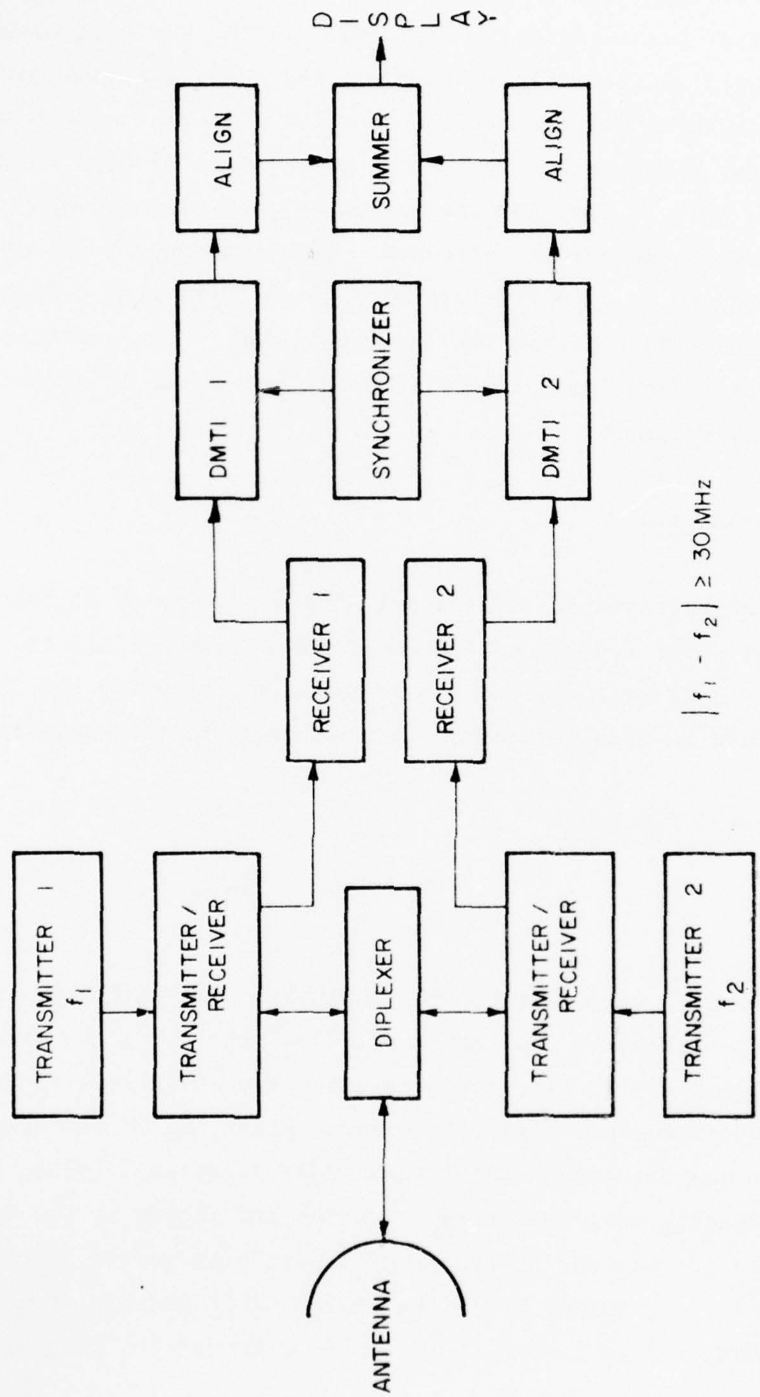


FIGURE 3. DUAL-FREQUENCY-DIVERSITY RADAR.

Dual-frequency diversity improves this situation by viewing the target at two separate frequencies. If the two frequencies are separated sufficiently ($\sim$ 30 MHz), the nulls and peaks of the target scattering characteristics occur at different aspect angles. Thus, on any given antenna scan, the probability of both signals being in a null is low, and the average signal strength out of the diversity combiner is increased. This improvement in average signal strength is approximately 6 dB for a 90-percent probability of detection. Part of the improvement is due to the increased average power from using two pulses and part is due to reduction in scintillation.

System Parameters

The characteristics of the new ARSR-3 are listed in TABLE 2. The output power tube is a klystron tunable between 1250 and 1350 MHz. A theoretical derived emission spectrum for the ARSR-3, using a 0.14-μs rise and decay time, was used in the analysis.

SITE ANALYSIS PROCEDURE

Approach

Five sites were selected for analysis. The following approach was used to determine the impact on EMC of replacing the existing radar at each of the five sites selected for analysis with an ARSR-3 dual-frequency-diversity radar. First, an interference threshold was determined for L-Band radar receivers. Next, the electromagnetic environment in which the FAA radars at the selected sites must operate was generated by identifying radars located in the vicinity, currently operating in the 1250-1350 MHz frequency band. Then, for each site, the impact on EMC of introducing an

TABLE 2

ARSR-3 EQUIPMENT CHARACTERISTICS

Transmitter[a]	
Source	Klystron
Frequency:	Tunable 1250 to 1350 MHz
Peak Power:	5 MW
Pulse Characteristics:	
Pulse Width	2 μs
Rise Time	0.14 μs
Decay Time	0.14 μs
Repetition Frequency	310 to 365 pps
Antenna	
Gain, low beam feed	34.5 dB
Gain, high beam feed	33.5 dB
Azimuth Beamwidth	1.1°
Elevation Pattern	Modified CSC^2
Polarization	Horizontal/Vertical/Circular
Rotation Speed	5 RPM
Receiver	
Sensitivity	-112 dBm
Bandwidth	500 kHz
Image Rejection	60 dB

[a] For each transmitter.

ARSR-3 was determined by calculating the expected level of interference of the existing radar at the site and of each radar in its environment using the existing frequency assignment. This value was then compared with the expected level of interference of an ARSR-3 installed at the site and of each radar in its environment using a frequency assignment that would accomodate the ARSR-3. The level of interference, calculated in terms of pulses/scan, was used to assess both the existing EMC and the impact of introducing the new radars.

Interference Criteria

For search radars, the threshold of visibility for uncorrelated interference pulses is approximately 10 dB above the receiver noise level.[3] For interference sources of the same PRF, the threshold of visibility is approximately equal to receiver noise. The interference criterion is an estimate of the number of visible interference pulses per scan which can be tolerated. It was originally anticipated that FAA would supply a threshold interference criterion from a NAFEC study project. However, results from the NAFEC study could not be provided in time to be used in this analysis. In a previous study for FAA (Reference 1), two criteria were used to bracket the problem since the exact amount of interference which can be tolerated is unknown. The two criteria correspond to coupling between two rotating antennas such that pulses are coupled at an observable level 5% and 1.6% of the time. This corresponds to 200 pulses/scan and 64 pulses/scan for radars with ARSR characteristics. The criteria have been used here in two ways. In one case, the

[3]Skolnik, M., *Radar Handbook*, p. 2-20, McGraw Hill, New York, NY, 1970.

equipment interactions were considered one at a time. Then a propagation loss which is exceeded 95% of the time was used for determining coupled signal levels. This reduced the percentage of time when multiple strobes are received to a tolerable level. The long term propagation statistics will determine the percentage of time that the criteria (based on observed pulses per scan) are exceeded. In the other case, a cumulative pulse count from several equipments is calculated with the sum compared against the pulse count criteria. Then a 50% or median propagation loss was used. This gives an average pulse count.

The above criteria were originally used for airport surveillance radars (ASR). These have a higher PRF corresponding to a shorter range and a higher scan rate than the long-range radars in this analysis. However, these two parameter changes tend to cancel each other and give a comparable number of pulses/scan for both radar types. Therefore, the above antenna coupling levels were converted to pulse-per-scan criteria which are applicable to both types of radars. The corresponding thresholds are still 200 pulses/scan and 64 pulses/scan.

Environment Generation

The ECAC data files were first searched for the records of radars operating in the 1250-1350 MHz frequency band and located within a 200-statute mile radius of the FAA sites being analyzed. Then, the ECAC data files were searched for the records of radars operating in the 1250-1350 MHz frequency band located between 200 and 500 statute miles of the FAA sites and using the same PRF as the radar at the sites being analyzed. The 200-statute mile and 500-statute mile distance radii are derived in APPENDIX C.

Pertinent information contained in the identified records was checked for completeness and accuracy. Any record missing information or that appeared to contain inaccurate data was validated by contacting the appropriate authorities. Discrete operating frequencies were often missing from the records and were obtained through phone conversations with the operating agency.

Equipments used as back-up, low usage tactical equipments, and other special function equipment with low usage were eliminated from further analysis unless they were of special significance, such as equipment that could cause high levels of interference.

Interference Prediction

Once a representative environment was generated, the level of interference presently being experienced by each radar in this environment was calculated and compared with the level of interference expected if the existing FAA radar at the selected site was replaced with an ARSR-3.

For the FAA radars, the interference was calculated in terms of pulse count. Pulse count is defined as the number of undesired pulses from one or more interfering transmitters entering a victim radar receiver above a given threshold during one scan of the victim antenna. The Air Force defines five scope conditions for reporting interference to manually operated radars.[4] These five scope conditions range from Condition 1, where few or no interference pulses are present on the scope, to Condition 5, where

[4] *Frequency Management and Electromagnetic Compatibility*, AFM 100-31, Department of the Air Force, Washington, DC, March 1970.

heavy interference clutter is present over most of the scope display. ECAC has developed a technique for estimating scope conditions based on the number of interfering pulses entering a victim receiver during one scan of its antenna and their power levels above the receiver interference threshold.

In this analysis, pulse count was used as a measure of interference to FAA radars. Both pulse count and scope condition were used as a measure of interference to military radars in the environment. The procedure used to calculate pulse count is explained in the following section. The procedure used to calculate scope condition is discussed in APPENDIX D.

Calculation of Pulse Count. To determine the pulse count of a particular radar receiver due to interference from several radar transmitters, it was necessary to first calculate the expected strength of the individual interfering signals at the victim receiver and the distribution of signal strength about the expected value. The expected strength of an interfering signal was calculated using the following equation:[5]

$$\overline{P}_R = P_T + \overline{G}_T + \overline{G}_R - L_P - F_{\Delta f} - C_{BW} \qquad (1)$$

where

$\overline{P}_R$ = the mean of the effective peak interference power at the victim receiver, in dBm

P_T = the interfering transmitter peak output power, in dBm

[5]Newhouse, P. D., *Peak Output Power in a Victim Receiver*, Radar Analysis Bulletin No. 2, ECAC, Annapolis, MD, May 1969.

$\overline{G}_T$ = the mean interfering transmitter antenna gain in the direction of the victim receiver, in dBi

$\overline{G}_R$ = the mean victim receiver antenna gain in the direction of the interfering transmitter, in dBi

L_P = the propagation path loss between two isotropic antennas, in dB

$F_{\Delta f}$ = the interfering signal attenuation as a function of frequency separation between the tuned frequency of the interfering transmitter and the victim receiver, in dB

C_{BW} = the bandwidth correction factor.

The propagation path loss, L_P, was calculated using a terrain-dependent computer model (TIREM). The topographic data was extracted from the ECAC terrain file. In some instances, when greater accuracy was required, topographic data was manually extracted from smaller scale maps (24,000:1) and used for the path loss calculations.

The bandwidth correction factor (C_{BW}) is due to the relative width of the receiver IF bandwidth and transmitter emission bandwidth of equipments in the environment. The interfering signal attenuation, $F_{\Delta f}$, for the frequencies of interest, is equal to the interfering transmitter emission spectrum attenuation. FIGURE 4 is a plot of the relative emission spectrum of typical L-Band transmitters. The spectrums shown are for transmitters which use pulse widths of 1.4 μs, 2 μs, and 6 μs with an assumed rise and fall time of .025 μs. These spectrums were drawn with a 20 dB per decade slope after the first break point and a 30 dB per decade slope after the second. The 30 dB per decade slope was selected instead of the more common 40 dB

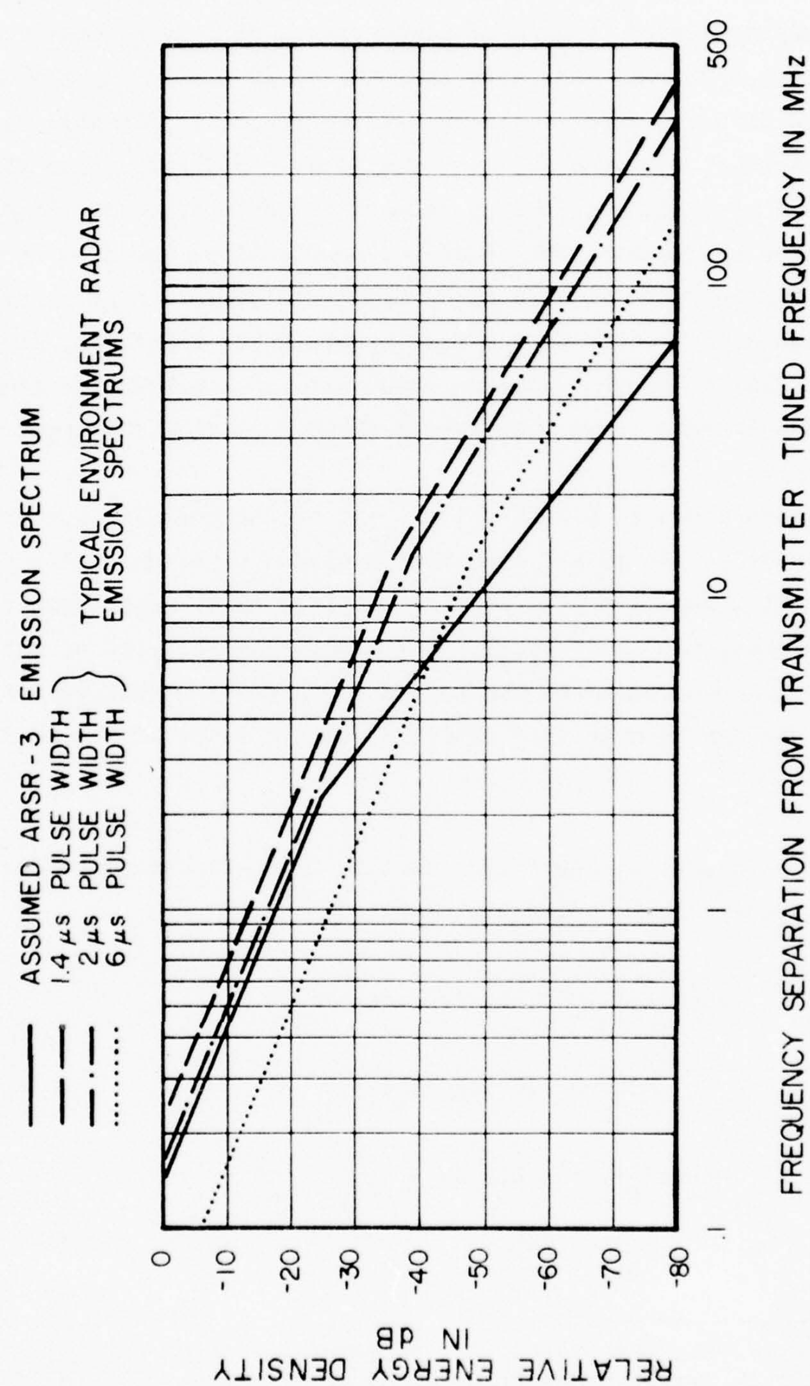


FIGURE 4. RELATIVE TRANSMITTER EMISSION SPECTRUM.

decade slope used in the Mason-Zimmerman spectrum model because a study performed by ECAC of measurements of conventional magnetron emission spectrums indicates that the 40 dB per decade attenuation of the emission spectrum, although theoretically possible, is not, in practice, achieved and that the 30 dB per decade slope with an assumed rise time of .025 μs is more representative of the actual emission spectrum.[6] The 30 dB per decade slope was also assumed for existing transmitters using klystrons because a check of available data at ECAC on L-Band radars using klystrons, indicates that a 30 dB per decade slope with an assumed rise time of .025 μs is more representative of the actual emission spectrum.

Also shown in FIGURE 4 is a plot of the emission spectrum of the ARSR-3. The ARSR-3 transmitter uses a klystron with a pulse width of 2 μs and a 0.14-μs rise and fall time. With good design techniques, the theoretical 40 dB per decade fall-off of the emission spectrum after the second break point should be achievable and was used in this analysis for the slope of the ARSR-3 spectrum.

The bandwidth correction factor, C_{BW}, was calculated using the appropriate equation listed below:

when $B_r T_i \leq 1$ and Δf = any value

$$C_{BW} = 20 \log (B_r T_i), \tag{2}$$

when $B_r T_i \geq 1$ and $\Delta f \leq \frac{1}{\pi T_i} + \frac{B_r}{2}$

$$C_{BW} = 0, \tag{3}$$

[6]Tabor, F. H., and Damien, D., *An Emperical Model of the Conventional Magnetron Transmitter Emission Spectrum*, ECAC-TN-74-21, ECAC, Annapolis, MD, September 1974.

and when $B_r T_i \geq 1$ and $\Delta f > \frac{1}{\pi T_i} + \frac{B_r}{2}$

$$C_{BW} = 20 \log (B_r T_i) - 6 \text{ dB} \qquad (4)$$

where

B_r = the 3-dB bandwidth of the victim receiver, in Hz

T_i = the pulse width of the interfering signal, in seconds

Δf = the frequency separation between the interfering transmitter tuned frequency and the victim receiver tuned frequency, in Hz.

Each parameter in Equation 1 has a degree of uncertainty associated with it and some of the parameters vary with time. The effective peak interference power is, therefore, a distribution of values.

On a scan-to-scan basis (the unit of time to measure pulse count and scope condition), only the gains of the transmitting and receiving antennas will vary significantly. It was assumed, therefore, that the effective peak interference power varies proportionally as a function of the mutual antenna gain between the interfering transmitter and the victim receiver antennas. The sector distribution of pulses was not calculated or considered in this analysis. This is not a differential factor between pre- and post-ARSR-3 deployment.

Given the receiver threshold for interfering signals, P_{RT}, the mean effective peak interference power, $\overline{P}_R$, and its distribution about the mean, the pulse count can be determined. Referring

to FIGURE 5, it can be seen that for a given interfering transmitter and victim receiver, only those pulses with a value of interference power (P_{Ri}) greater than or equal to P_{RT} (shaded portion of curve), will cause interference. If $P_{RT} = \overline{P}_R + \Delta$ then a pulse will cause interference, provided $P_{Ri} \geq \overline{P}_R + \Delta$. Since interference power is assumed to vary as a function of the mutual antenna gain only, and since $\overline{P}_R$ was calculated using mean antenna gain, a given pulse will cause interference if the mutual antenna gain at the time of transmission ($G_{Ti} + G_{Ri}$) is greater than or equal to the mean mutual antenna gain plus Δ dB. That is interference will occur if:

$$G_{Ti} + G_{Ri} \geq \overline{G}_T + \overline{G}_R + \Delta.$$

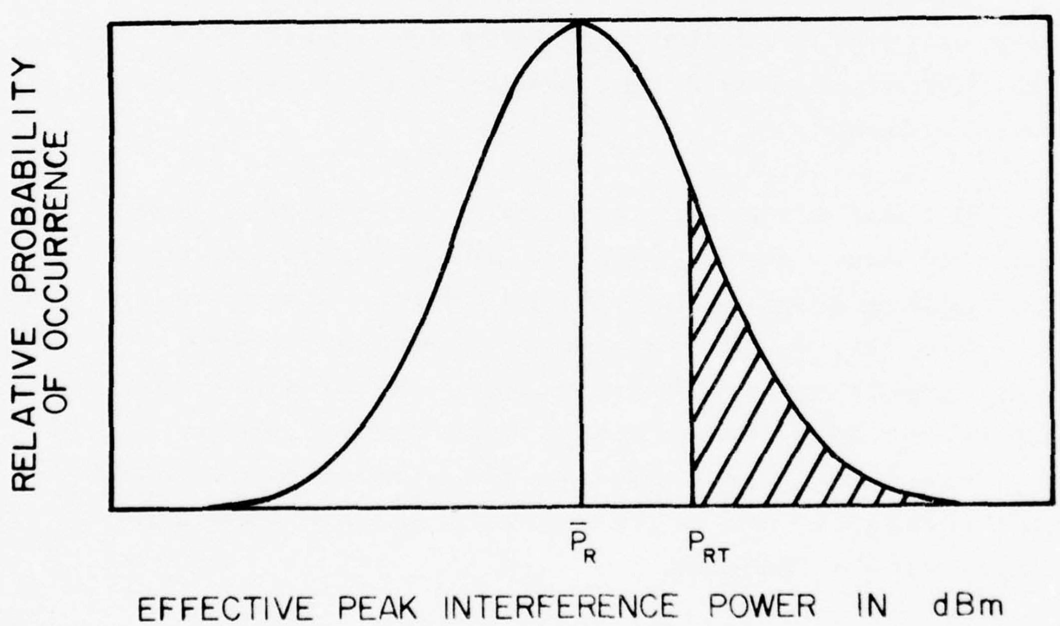


FIGURE 5. DISTRIBUTION OF EFFECTIVE PEAK INTERFERENCE POWER.

The probability of a given pulse causing interference is, therefore, equal to the probability of the mutual antenna gain at the time of transmission being greater than or equal to the mean mutual antenna gain plus Δ dB. FIGURE 6 is a graph of the mutual antenna gain versus the cumulative probability of occurrence for two typical L-Band radar antennas. The graph gives the probability that a given mutual antenna gain level, relative to the mean mutual antenna gain level, will be equaled or exceeded. It was generated by convolving the measured antenna patterns of the AN/FPS-8 and the AN/TPS-1B radars. These were selected as being representative of the ARSR patterns and of typical patterns for environmental radars. Also shown on the graph is an approximation of the mutual antenna gain assuming a normal probability distribution with a 13-dB sigma.

The expected number of pulses from a single source capable of causing interference during one scan of the victim's antenna is equal to the probability of the mutual antenna gain being greater than or equal to the mean plus Δ dB times the number of pulses transmitted during the scan. The pulse count is then ascertained by adding the number of interfering pulses from each individual transmitter in the environment.

The cumulative probability distribution of mutual antenna gain shown in FIGURE 6 was used when the pulse count of FAA receivers was calculated. But to facilitate use of the computer, the normal distribution approximation, also shown in FIGURE 6, was used when the pulse count of military receivers was calculated. Military operations envolving radars, can generally be accomplished at higher interference pulses counts than can FAA operations. Therefore, the normal distribution is in close agreement with the other distribution in the regions where it was utilized.

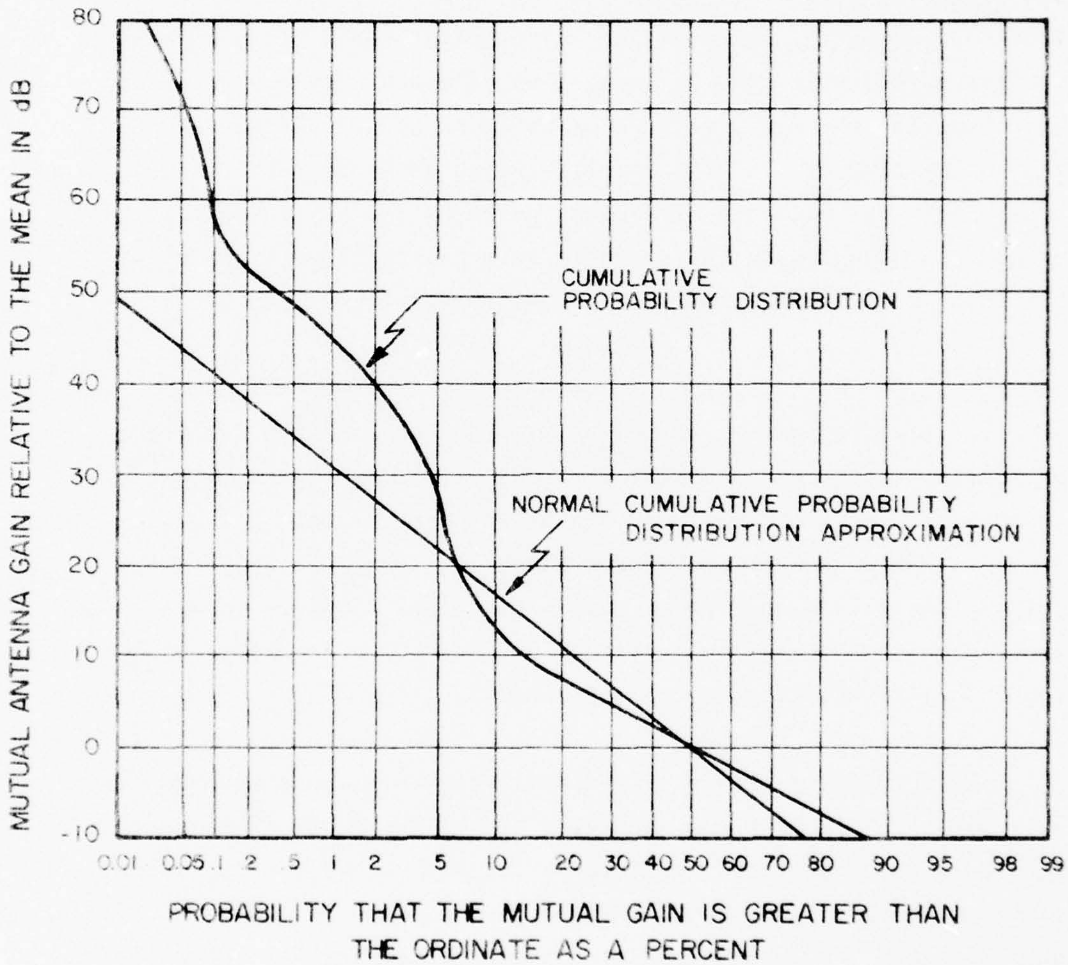


FIGURE 6. CUMULATIVE PROBABILITY DISTRIBUTION OF MUTUAL ANTENNA GAIN.

For the ARSR-3, the pulse counts of first one channel, then the other operating at their respective frequencies were determined and then added together to arrive at the total pulse count of the radar. In general the source will be closer in frequency to one channel and the pulse count in this channel will dominate the sum. If the source frequency is halfway between such that the count is the same in both channels, the receivers actually delay one channel such that the interference is displayed at two points on the display. In either case, summing the two channels gives the correct answer for the number of displayed interference pulses.

A sample calculation of pulse count is provided in TABLE 3 using the San Pedro Hill environment. Column 1 gives the assigned number of each equipment. Columns 2-6 give the appropriate values for the terms of Equation 1. Column 7 is the calculated mean effective peak interference power. Column 8 gives Δ, the number of dB the interference power threshold (P_{RT}) is from mean effective interference power (P_R) or, as was shown above, that value which when added to the mean mutual antenna gain gives the threshold mutual antenna gain which must be equaled or exceeded before interference will occur. Column 9 gives the probability as a percent of the mutual antenna gain being greater than or equal to the threshold (the mean mutual antenna gain plus Δ dB). In this example, the pulse count of an FAA radar is being enumerated so the mutual antenna gain cumulative probability distribution shown in FIGURE 6 was used. Column 10 gives the PRF of the interfering transmitter. Column 11 gives the expected number of pulses from the interfering transmitter capable of causing interference per scan of the victim receiver antenna. At the bottom of the page is the pulse count.

TABLE 3

CALCULATION OF PULSE COUNT FOR THE EXISTING SAN PEDRO HILL RADAR

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	L_P (dB)	$F_{\Delta f}$ (dB)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	$P_{RT}{}^{a} - \overline{P}_R$ (dB)	Prob. (%)	PRF (PPS)	Interfering Pulses/Scan[b]
2[c]	91.5	-26.5	134	48.9	0	-118	16	8.0	800	640
3B	93.4	-26.5	139	64.7	9.6	-127	25	5.3	345	183
4	96.0	-26.5	152	56.5	0	-139	37	2.6	360	94
5B	90.8	-26.5	213	58.5	6.5	-201	99	0	267	0
6	87.0	-26.5	161	54.2	0	-155	53	.22	600	13
7A	94.0	-26.5	213	51.5	9.6	-187	85	0	360	0
7B	94.0	-26.5	213	71.1	9.6	-208	106	0	360	0
8	100.0	-26.5	165	38.6	9.6	-120	18	7.0	241	169
9	90.0	-26.5	187	51.0	0	-174	72	.048	800	4
10B	97.0	-26.5	200	55.2	0	-185	83	.02	260	0
11	96.0	-26.5	202	35.6	0	-168	66	.07	280	2
12	100.0	-26.5	205	74.1	9.6	-196	94	0	241	0
								Pulse Count = 1105		

[a] P_{RT} = -102 for the San Pedro Hill Radar.

[b] Scan interval of the San Pedro Hill Radar = 10 s/scan.

[c] Equipment #2 is low usage.

SUITLAND SITE ANALYSIS

Introduction

The Suitland FAA radar site is located southeast of Washington, DC. This site is scheduled for conversion to an ARSR-3 during the initial phase of the FAA's modernization plan. Suitland was chosen for analysis because of its relatively dense environment which requires careful frequency assignment. At present, the Suitland radar operates on one of two assigned frequencies, 1307 or 1315 MHz. Since the ARSR-3 employs dual-frequency diversity and requires a separation of 30 MHz, at least one of the frequencies at Suitland would have to be changed. Assignment of a different frequency required analysis of the environment to preclude interference with existing equipments.

Suitland Electromagnetic Environment

The Suitland environment was generated using equipment records from ECAC data files. From this list of equipments, a current list of the operational environment was created. TABLE 4 lists radars within 200 miles of Suitland and TABLE 5 lists radars between 200 and 500 miles of Suitland with the same PRF as Suitland's radar. Equipments are numbered according to the distance from Suitland. Information given in both tables includes frequency, operating agency and site location, equipment nomenclature, peak transmitter power (P_T), pulse repetition frequency (PRF), pulse width, receiver interference threshold (P_{RT}), receiver scan rate, latitude and longitude, and distance separation. Radars operating on one of two assigned frequencies are identified with two numbers, i.e., #8A and #8B for Trevose, PA. When calculating scope conditions

TABLE 4

RADARS WITHIN 200 MILES OF SUITLAND, MD.

Equipment Number	Operate Frequency (MHz)	Operating Agency and Site	Equipment Nomenclature	P_T (dBm)	PRF (PPS)	Pulse Width (μs)	P_{RT} (dBm)	Scan Rate (RPM)	Latitude (N) Longitude (W) (deg-min-sec)	Distance Separation (Statute Miles)
1A 1B	1307 1315	FAA Suitland, MD	ARSR-1E	96	355	2	-102	6	38-51-14 76-56-22	0
2A 2B	1270 1330	Air Force Ft. Meade, MD	AN/FPS-67B	94	370	6	-104	5	39-06-59 76-43-39	21
3	1275	Marine Quantico, VA	AN/UPS-1F	91.5	800	4.2	-95	15	38-30-07 77-18-11	31
4	1275	Navy Patuxent NAS, MD	AN/TPS-1D	87	380	2	-94	15	38-17-15 76-24-04	49
5A 5B	1275 1335	FAA Cape Charles, VA	AN/FPS-7B	100	244	6	-100	5	37-08-02 75-57-04	130
6A 6B	1305 1325	FAA Elwood City, NJ	ARSR-2	96	360	2	-102	6	39-35-19 74-41-56	130
7	1300	Marine Willow Grove, PA	AN/UPS-1C	90	800	1.4	-95	8	40-11-59 75-08-40	133
8A 8B	1300 1335	FAA Trevose, PA	ARSR-60	93.4	365	2	-104	5	40-08-05 74-59-14	136
9	1290	Air Force University Park, PA	AN/MPS-11	90.8	360	3	-102	10	40-48-30 77-52-40	143
10A 10B	1270 1330	FAA Bedford, VA	AN/FPS-67B	94	360	6	-104	5	37-31-02 79-30-39	167
11A 11B	1260 1330	FAA Benton, PA	AN/FPS-20M	93.4	360	3	-104	5	41-21-26 76-17-36	176

TABLE 5

RADARS WITHIN 500 MILES OF SUITLAND, MD WITH PRF = 355 PPS

Equipment Number	Operate Frequency (MHz)	Operating Agency and Site	Equipment Nomenclature	P_T (dBm)	PRF (PPS)	Pulse Width (μs)	P_{RT} (dBm)	Scan Rate (RPM)	Latitude (N) Longitude (W) (deg-min-sec)	Distance Separation Statute Miles
1A	1307	FAA	ARSR-1E	96	355	2	-102	6	38-51-14	0
1B	1315	Suitland, MD							76-56-22	
12A	1310	FAA	AN/FPS-67B	94	355	6	-104	5	40-23-56	201
12B	1330	Oakdale, PA							80-09-26	
13A	1320	FAA	ARSR-2	96	355	2	-106	6	40-39-45	209
13B	1330	New York, NY							73-46-48	

and N-scores for a particular receiver, the transmitter frequency causing the worst interference was assumed to be operating, except for equipment #8 at Trevose, PA, which operates simultaneously on both frequencies (dual diversity). Calculations for receivers with two assigned frequencies were made twice, once for each operating frequency.

TABLE 6 lists the percent usage of radars in the Suitland environment. Columns 1 and 2 list the equipment numbers and operating agencies. Column 3 lists the transmitter radiation percentage that is the percentage of time during the week that the transmitter is actually radiating energy. Columns 4, 5, and 6 list the percentage of time the equipment is normally manned or on standby during the weekday daytime, weekday nighttime, and weekend respectively.

TABLE 6

PERCENT USAGE OF RADARS IN THE SUITLAND ENVIRONMENT

Equipment Number	Operating Agency	Transmitter (%)	Weekday (%)	Weeknight (%)	Weekend (%)
1A 1B	FAA	100	100	100	100
2A 2B	USAF	95	100	100	100
3	USMC	100	100	100	100
4	USN	10	60	10	12
5A 5B	FAA	99	100	100	100
6A 6B	FAA	95	33	33	33
7	USMC	25	2	8	80
8A 8B	FAA	100	100	100	100
9	USAF	10	100	100	100
10A 10B	FAA	99	100	100	100
11A 11B	FAA	99	100	100	100

Radars #4, #7, and #9 only operate a low percentage of the time. They were still included in the Suitland environment to evaluate their interference potential. Equipment #4 is a mobile radar operating within a 20-mile radius of Patuxent NAS, MD. For purposes of this analysis, #4 was assumed to be fixed at the center of its operating area. Even though its transmitter only radiates 10% of the time during the week, it was included in the environment because of its short distance from the Suitland radar (49 miles). Also #4 operates co-channel with an FAA radar located at Cape Charles, VA (#5A).

Equipment #7 is an AN/UPS-1C radar operated by the Marine Air Traffic Control Unit (MATU 73) at Willow Grove, PA. Despite its low usage, #7 was included due to its co-channel operation with #8A, an FAA radar at Trevose, PA, only 8 miles away. The Air National Guard operates #9, an AN/MPS-11, at University Park, PA. Number 9 was included because, according to site personnel, it consistently operates between 10 and 20 hours each week.

By including radars #4, #7, and #9 in the Suitland environment, it was assumed that they operate 100% of the time and represent potential interference sources. In this respect, the environment represents a worst case since at any one time, all of these radars may not actually be operating.

Other equipments were identified but not included in the Suitland environment. They include an AN/TPS-1D operated by the Naval Surface Weapons Center at Dahlgren, VA. According to local authorities, the AN/TPS-1D has "not been operated for over a year". A second radar at Quantico, VA, an AN/UPS-1B operated by the Marines, was identified but not included in the environment. It was found to have a very low usage of only 1-2 hours per week.

The finalized Suitland environment is shown on the map in FIGURE 7. The numbers correspond to the radars in TABLE 4. The L-Band spectrum for the Suitland environment is shown in FIGURE 8. Again, radars with more than one assigned frequency are denoted by a number-letter combination.

Pulse Count and Scope Conditions For Radars Between 0-200 Statute Miles of Suitland

The pulse count totals for the ARSR-1E presently in operation at Suitland are given in TABLE 7 and the detailed calculations are given in TABLES 8 and 9. The totals reflect the transmitters in the environment operating on the frequencies that would cause the most interference to the Suitland radar. For example, of the 579 pulses received on the first channel at Suitland, 518 are contributed by equipment #2B at Ft. Meade. If the radar at Ft. Meade was actually operating on its lower frequency (#2A), only 252 interfering pulses would be received. Similarly, for the second channel at Suitland of the 636 pulses received, 592 are contributed by equipment #2B. If 2A were operating, only 274 pulses would be received. It is evident that 89-93% of the interference at Suitland is caused by equipment #2 at Ft. Meade.

Also given in TABLE 7 are pulse counts for Suitland when the ARSR-3 is installed at Suitland and at Bedford, VA. Because the ARSR-3 is a dual-diversity radar, its pulse count is actually the sum of Channels 1 and 2. Interference from both receivers is processed by the common digitizer. Since the present frequencies assigned to the ARSR-1E only have an 8-MHz separation, a new frequency had to be chosen for the ARSR-3 that would provide the desired separation of 30 MHz. In addition, the new frequency should cause only minimal additional interference to other installed equipments and require as few changes as possible to the existing frequency assignment.

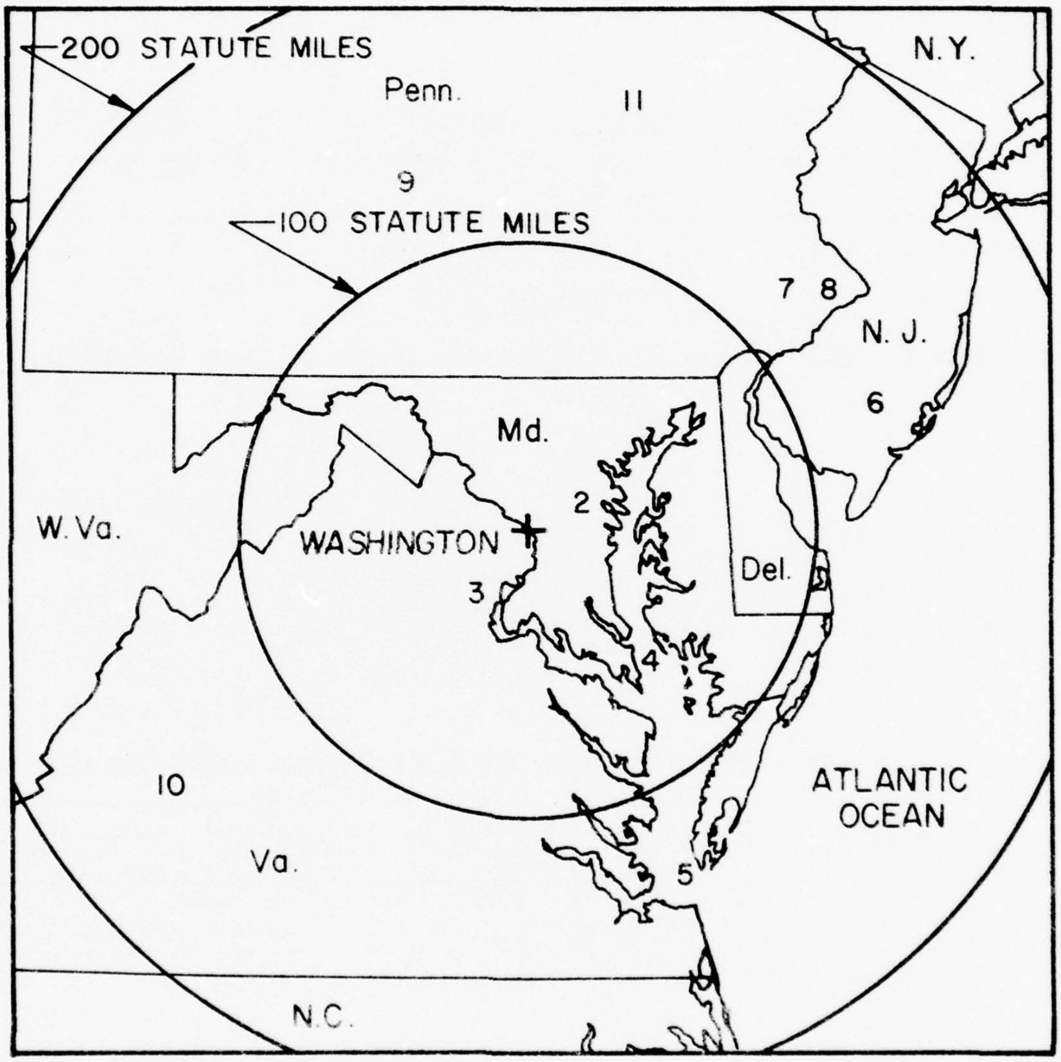


FIGURE 7. LOCATION OF RADARS IN THE SUITLAND ENVIRONMENT.

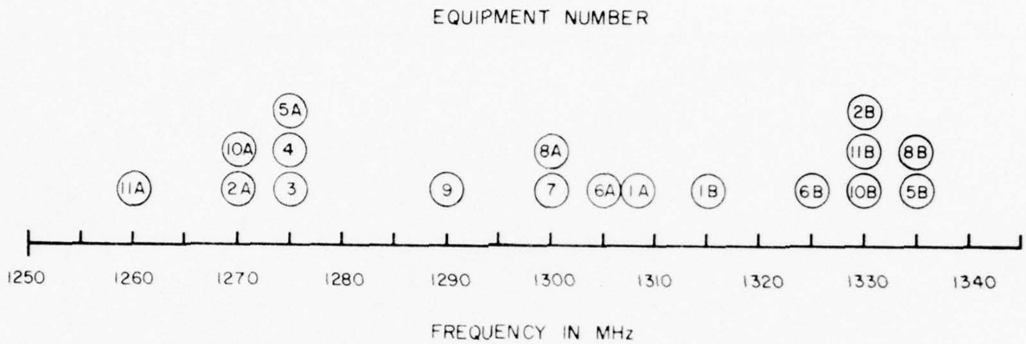


FIGURE 8. EXISTING FREQUENCY ASSIGNMENT IN THE SUITLAND ENVIRONMENT.

TABLE 7

PULSE COUNTS FOR THE EXISTING SUITLAND RADAR AND FOR ARSR-3 CONVERSION

Equipment Type	Operating Frequency of the First Channel (MHz)	Pulse Count of the First Channel (Pulses/Scan)	Operating Frequency of the Second Channel (MHz)	Pulse Count of the Second Channel (Pulses/Scan)	Pulse Count of the radar (pulses/scan)
ARSR-1E	1307	579	1315	636	636[a]
ARSR-3	1345	650	1315	764	1414

[a]This pulse count only includes pulses from the second channel since the ARSR-1E is not dual diversity.

TABLE 8

PULSE COUNT PREDICTIONS FOR THE ARSR-1E AT SUITLAND ON CHANNEL A

Equipment Number	P_T (dBm)	$\bar{G}_T + \bar{G}_R$ (dBi)	L_p (dB)	$F_{\Delta f}$ (dB)	C_{BW} (dB)	$\bar{P}_R$ (dBm)	$P_{RT}^{c} - \bar{P}_R$ (dB)	Prob.	PRF (pps)	N/scan[e] (pulses/scan)
2A 2B	94	-26.5	134	65.0[a] 55.4[a]	+9.6	-122 -112	20 10	.068 .14	370	251.6 518.0
3	91.5	-26.5	154[b]	62[d]	0	-151	49	.0043	800	34.4
4	87	-26.5	184	50.2	0	-174	72	.00045	380	1.7
5A 5B	100	-26.5	202	60.0 58.0	+9.6	-179 -177	77 75	.00031 .00037	244	0.8 0.9
6A 6B	96	-26.5	202	20.0 43.0	0	-152 -176	51 74	.0026 .00039	360	9.4 1.4
7	90	-26.5	201	30.0	0	-168	66	.00066	800	5.3
8A 8B	93.4	-26.5	189	33.0 48.7	0	-155 -171	53 69	.0014 .00055	365	5.1] Dual 2.0] Freq.
9	90.8	-26.5	201	45.4	+3.5	-178	77	.0003	360	1.1
10A 10B	94	-26.5	202	61.6 55.4	+9.6	-187 -180	85 78	.00013 .00028	360	0.5 1.0
11A 11B	93.4	-26.5	207	58.7 49.4	+3.5	-195 -186	93 84	0 .00014	360	0 0.5
									TOTAL	579

[a] From measured OT data.

[b] From special corrected TIREM.

[c] P_{RT} = -102.

[d] From UPS-1 spectrum signature.

[e] Scan interval of ARSR-1E = 10 s/scan.

TABLE 9

PULSE COUNT PREDICTIONS FOR THE ARSR-1E AT SUITLAND ON CHANNEL B

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	L_p (dB)	$F_{\Delta f}$ (dB)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	$P_{RT}^{c} - \overline{P}_R$ (dB)	Prob.	PRF (pps)	N/scan[e] (pulses/scan)
2A 2B	94	-26.5	134	62.0[a] 54.0[a]	+9.6	-119 -111	17 9	.074 .16	370	273.8 592.0
3	91.5	-26.5	154[b]	63.0[d]	0	-152	50	.0034	800	27.2
4	87	-26.5	184	53.5	0	-177	75	.00036	380	1.4
5A 5B	100	-26.5	202	62.6 53.6	+9.6	-182 -172	80 71	.00023 .00049	244	0.6 1.2
6A 6B	96	-26.5	202	36.0 36.0	0	-168	67	.00062	360	2.2
7	90	-26.5	201	37.2	0	-175	73	.00042	800	3.4
8A 8B	93.4	-26.5	189	40.3 44.0	0	-162 -166	60 64	.00087 .00071	365	3.2] Dual 2.6] Freq.
9	90.8	-26.5	201	50.0	+3.5	-183	81	.00021	360	0.8
10A 10B	94	-26.5	202	64.0 50.0	+9.6	-189 -175	87 73	.0001 .00042	360	0.4 1.5
11A 11B	93.4	-26.5	207	60.7 43.0	+3.5	-197 -180	95 78	0 .00028	360	0 1.0
									TOTAL	636

[a]From measured OT data.

[b]From special corrected TIREM.

[c]P_{RT} = -102.

[d]From UPS-1 spectrum signature.

[e]Scan interval of ARSR-1E = 10s/scan.

Suitland presently operates on 1315 MHz. Thirty MHz above this frequency is 1345 MHz that is unassigned and will provide the desired frequency separation. The pulse counts resulting from this assignment are found on line two of TABLE 7. With the ARSR-3 installed, this represents a 120% increase in pulse count over the ARSR-1E. The two major causes of the increase are the dual-diversity operation and the slower scan rate of the ARSR-3 as compared to the ARSR-1E.

A different frequency assignment for Suitland was not tried. Thus, the selected frequency assignment was to move equipment #1A from 1307 to 1345 MHz, requiring only one change to the existing assignments.

The effect of installing an ARSR-3 at Suitland on the other FAA radars in the environment is summarized in TABLE 10. Equipment numbers are listed in column 1, operating frequencies in column 2, pulse counts for the existing environment in column 3, and pulse counts after the ARSR-3 installation in column 4. As can be seen from the table, the level of interference at the other FAA radars either remained constant or actually decreased slightly. Therefore, the installation of an ARSR-3 operating at 1315 and 1345 MHz at Suitland will not degrade the performance of the other FAA radars.

The effect of the ARSR-3 on military radars in the Suitland environment is summarized in TABLE 11. Columns 1 and 2 list the equipment numbers and operating frequencies. Columns 3 and 4 list the pulse count, N-score, and scope conditions due to the existing environment and the future ARSR-3 environment. In all cases, the scope conditions did not change, while the pulse count

TABLE 10

PULSE COUNTS OF FAA RADARS IN THE SUITLAND ENVIRONMENT BEFORE AND AFTER CONVERSION TO THE ARSR-3

Equipment Number	Operating Frequency (MHz)	Pulse Count Due to Existing Environment	Pulse Count Due to ARSR-3 Operating at 1315 and 1345 MHz
5A	1275	563	563
5B	1335	126	125
6A	1305	489	483
6B	1325	308	307
8A	1300	718[a]	709[a]
8B	1335		
11A	1260	7	7
11B	1330	184	184

[a]Trevose pulse counts do not include pulses from low usage Willow Grove #7, but do include pulses from Orange, CT, and New York.

TABLE 11

PULSE COUNTS, N-SCORES, AND SCOPE CONDITIONS OF MILITARY RADARS IN THE SUITLAND ENVIRONMENT BEFORE AND AFTER CONVERSION TO THE ARSR-3

Equipment Number	Operating Frequency (MHz)	Pulse Count, N-Score and Scope Condition Due to Existing Environment			Pulse Count, N-Score, and Scope Condition if an ARSR-3 was installed in the Environment		
2A	1270	656	.3	(1)	67	.0	(1)
2B	1330	1922	1.3	(1)	790	.3	(1)
3	1275	182	.0	(1)	75	.0	(1)
4	1275	165	.0	(1)	165	.0	(1)
7	1300	2716	4.4	(2)	2716	4.4	(2)
9	1290	0	.0	(1)	0	.0	(1)

decreased in about half of the equipments. Assignment of 1345 MHz as the second frequency at Suitland will not increase the level of interference to the military radars in the Suitland environment.

The only scope Condition 2 in TABLE 11 is predicted for equipment #7 at Willow Grove, PA, for both the existing and the ARSR-3 environments. The primary source of the interference that caused this condition is the FAA radar (#8) at Trevose, PA, only 8 miles away. In addition to the close proximity, equipments #7 and #8A operate on the same frequency. The co-channel operation and the short distance between them causes a high number of interference pulses, hence the scope Condition 2. Equipment #7 at Willow Grove is a very low usage radar but was included because when it is operating, equipments #7 and #8 pose serious interference problems for each other.

Radars Between 200-500 Miles with the Same PRF

Only two radars between 200-500 miles of Suitland were found with correlated pulses. One is an FAA radar located close to Oakdale, PA, and the other is also an FAA radar located at JFK Airport in New York. APPENDIX C states that L-Band radars greater than 200 miles apart can cause interference only if their signals are correlated and that radars farther than 500 miles apart have a very low probability of interfering with one another. The Oakdale and JFK radars operate with the same PRF as Suitland but have enough frequency separation to prevent interference.

Summary

Only one radar (Ft. Meade, MD) was identified that exceeded the interference criterion of 200 pulses per scan for Suitland. The total pulse count from all equipments was calculated to be

between 312 pulses per scan and 636 pulses per scan depending upon which Suitland channel and which Ft. Meade channel was being used. The other FAA radars in the environment had lower pulse counts except the Trevose, PA, radar that is analyzed in a separate section.

The calculated interference levels for the active military radars were all scope Condition 1.

Site Prediction Validation

On February 27, 1975, ECAC personnel visited the FAA radar site at Suitland, MD, to validate interference levels and compare them with pulse count predictions. TABLES 8 and 9 tabulate Suitland pulse counts predicted from each radar in the environment.

Equipment #2 at Ft. Meade was predicted to contribute 252 pulses on channel A and 518 pulses on channel B. As discussed earlier, the Ft. Meade equipment should be the primary source of interference and represents the highest level of coupling. The type of coupling predicted between Ft. Meade and Suitland is mainbeam-to-sidelobe coupling. This type of coupling would be manifested by pulse sectors in the general bearing of Ft. Meade (032° True) as viewed on the Suitland scope. Interference concentrated as strobes around 032° True with the video integrator off was observed during the site visit on almost every sweep.

Quantico (#3) initially was predicted to cause a high level of coupling. This was not verified by the site visit. It was found that Quantico represents a much lower level of coupling. Strobes from Quantico were only observed approximately every 5th sweep. In an effort to resolve the discrepancy, two items were checked in the calculation, one the propagation loss and the

other the transmitter off-frequency rejection (OFR). It was found that the path was very close to line of sight and very accurate terrain data was needed to get the correct propagation loss. This data was manually extracted from 1-24,000 scale maps that are more accurate than ECAC's automated data base. Also the OFR was checked and compared to measured data and found to be conservative. With these two revisions, the calculated interference level agrees with the observed levels.

All other radars in the Suitland environment were predicted to the much lower levels of coupling than either the Ft. Meade or Quantico radars. Occasional interference strobes were observed from these radars at random intervals.

Interference strobes concentrated around 110° True were observed at about the same level of coupling as Quantico. However, ECAC records had not identified any radar in that general direction from Suitland. Using detailed maps, the Naval Research Lab Annex at Chesapeake Beach was determined to be on the 110° True radial from Suitland. Contact was made with local authorities and it was verified that an L-Band radar, an AN/SPS-12, was indeed operating at that location in the frequency band, 1250-1350 MHz. The AN/SPS-12 is used on an experimental basis for about 6 hours per day. Since fixed equipments in operation for less than six months from installation to deactivation are exempt from reporting to ECAC, the radar at Chesapeake Beach had not been reported. All radars, not just Suitland, are susceptible to this kind of interference from experimental or temporary equipments.

TREVOSE SITE ANALYSIS

Introduction

The Trevose, PA, radar is a one-of-a-kind (ARSR-60) unit, operating in a dual-frequency-diversity mode. The assigned frequencies for Trevose are 1300 and 1335 MHz. Transmitter A is delayed 4 μs from transmitter B, and each channel uses a different antenna polarization. The combined received pulses are processed by a standard common digitizer and fed to the New York ATCC and the NAFEC Center. The ARSR-60 will not be replaced by an ARSR-3 during the initial upgrade phase.

Trevose Electromagnetic Environment

The Trevose environment is almost identical to the Suitland environment. Equipments #5 at Cape Charles, VA, and #10 at Bedford, VA, were deleted from the environment since they were beyond 200 miles, while equipments #14 at Orange, CT, and #15 at New York City were added since they were closer than 200 mi. TABLE 12 lists radars within 200 miles of Trevose using the same numbers as assigned to the radars in the Suitland environment, but ordered by their distance from Trevose.

Pulse Count for the Trevose Radar

The number of interference pulses predicted for Trevose is in TABLE 13. Listed are pulses for both the present environment and the future environment with an ARSR-3 installed at Suitland, MD. The last column lists the total pulses received on both channels, since #8 at Trevose is a dual-diversity radar. Installation of an ARSR-3 at Suitland has a negligible effect on the radar at Trevose. The number of received pulses decreases slightly when the ARSR-3 is introduced.

TABLE 12

RADARS WITHIN 200 STATUTE MILES OF TREVOSE

Equipment Number	Operate Frequency (MHz)	Operating Agency and Site	Equipment Nomenclature	P_T (dBm)	PRF (PPS)	Pulse Width (μs)	P_{RT} (dBm)	Scan Rate (RPM)	Latitude (N) Longitude (W) (deg-min-sec)	Distance Separation (Statute Miles)
8A 8B	1300 1335	FAA Trevose, PA	ARSR-60	93.4	365	2	-104	5	40-08-05 74-59-14	0
7	1300	Marine Willow Grove, PA	AN/UPS-1C	90	800	1.4	-95	8	40-11-59 75-08-40	9
6A 6B	1305 1325	FAA Elwood City, NJ	ARSR-2	96	360	2	-102	6	39-35-19 74-41-56	40
15A 15B	1320 1330	FAA NYC, NY	ARSR-2	96	355	2	-106	6	40-39-45 73-46-48	73
11A 11B	1260 1330	FAA Benton, PA	AN/FPS-20M	93.4	360	3	-104	5	41-21-26 76-17-36	108
2A 2B	1270 1330	Air Force Ft. Meade, MD	AN/FPS-67B	94	370	6	-104	5	39-06-59 76-43-39	116
4	1275	Navy Patuxent NAS, MD	AN/TPS-1D	87	380	2	-94	15	38-17-15 76-24-04	128
14	1300	FAA Orange, CT	AN/TPS-44	90.8	267	4.2	-100	15	41-16-03 72-59-34	130
1A 1B	1307 1315	FAA Suitland, MD	ARSR-1E	96	355	2	-102	6	38-51-14 76-56-22	136
9	1290	Air Force University Park, PA	AN/MPS-11	90.8	360	3	-102	10	40-48-30 77-52-40	158
3	1275	Marine Quantico, VA	AN/UPS-1F	91.5	800	4.2	-95	15	38-30-07 77-18-11	168

TABLE 13

PULSE COUNTS FOR THE TREVOSE RADAR

Equipment Type	Operating Frequency of the First Channel (MHz)	Pulse Count of the First Channel (pulses/scan)	Operating Frequency of the Second Channel (MHz)	Pulse Count of the Second Channel (pulses/scan)	Pulse Count of the Radar (pulses/scan)
Existing	1300	9732	1335	624	10356[a]
ARSR-3 (at Suitland)	1300	9726	1335	622	10348[a]

[a]This is a total of channels one and two since Trevose is a dual diversity radar.

A breakdown of the pulse count in TABLE 13 is given in TABLES 14 and 15. The calculations indicate that equipment #7 at Willow Grove, PA, is the major source of interference at Trevose. The high number of interference pulses is caused by the short distance (9 miles) between the radars and by the on-tune operation of one channel at Trevose. However, it was later verified that this equipment seldom operates. Trevose's pulse count without #7 in the environment is given in TABLE 16.

Prediction Validation

Personnel from ECAC visited the FAA radar at Trevose, PA, on March 27, 1975. The purpose of the visit was to observe the levels of interference encountered and compare them with ECAC predictions. Analysis based on ECAC records of the environment indicated that without #7, the level of coupled interference at Trevose would probably be limited to narrow strobes. These occur when, as the several antennas are rotating, mainbeam-to-sidelobe coupling occurs. This was the level of coupling that was observed at Trevose. Narrow strobes were found in the general direction of Elwood City, NJ (#9), New York City, NY (#15), and Orange, CT (#14). It was not possible to separate #15 and #14 based on bearing. Interference from other equipments, predicted to occur at a lower level of coupling, was also observed during the visit.

TABLE 14

PULSE COUNT PREDICTIONS FOR THE ARSR-60 AT TREVOSE, PA, ON CHANNEL A

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	L_p (dB)	$F_{\Delta f}$ (dB)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	$P_{RT}{}^c - \overline{P}_R$ (dB)	Prob.	PRF (PPS)	N/Scan[a] ARSR-1E	OFR	N/Scan[b] ARSR-3
1A 1B	96	26.5	189	-33.1 -40.6	-6.0	-159 -166	55 62	.0011 .0008	355	4.7 3.4	75.0 56.0	0 1.3
2A 2B	87	26.5	184	-59.0 -59.0	0	-182 -182	78 78	.00028 .00028	370	1.2 1.2	59.0 59.0	1.2 1.2
3	91.5	26.5	192	-53.0	0	-180	76	.00033	800	3.2	53.0	3.2
4	87	26.5	191	-47.2	-6.0	-184	80	.00022	380	1.0	47.2	1.0
6A 6B	96	26.5	159	-30.0 -47.2	-6.0	-126 -142.7	22 39	.062 .022	360	267.8 95.0	30.0 47.2	267.8 95.0
7	90	26.5	142	0	-9.1	-87.6	-16	.966	800	9273.6	0	9273.6
9	90.8	26.5	196	-39.5	-2.5	-173.7	70	.00052	360	2.2	39.5	2.2
11A 11B	93.4	26.5	185	-56.6 -52.8	-2.5	-177 -173.4	73 69	.00042 .00054	360	1.8 2.3	56.6 52.8	1.8 2.3
14	90.8	26.5	194	0	0	-129.7	26	.053	267	169.8	0	169.8
15A 15B	96	26.5	186	-44.4 -49.6	-6.0	-166.9 -172	63 68	.00076 .00059	355	3.2 2.5	44.4 49.6	3.2 2.5
									TOTAL	9732.4	TOTAL	9726

[a] Scan interval of ARSR-60 is 12 s/scan.

[b] This column indicates the pulse count at Trevose with an ARSR-3 installed at Suitland.

[c] $P_{RT} = -104$.

TABLE 15

PULSE COUNT PREDICTIONS FOR THE ARSR-60 AT TREVOSE, PA, ON CHANNEL B

Equipment Number	P_T (dBm)	$G_T + G_R$ (dBi)	L_p (dB)	$F_{\Delta f}$ (dB)	C_{BW} (dB)	P_R (dBm)	P_{RT}[c] - P_R (dB)	Prob.	PRF (PPS)	N/Scan[a] ARSR-1E	OFR	N/Scan[b] ARSR-3
1A 1B	96	26.5	189	48.9 44.4	-6.0	-174 -169.9	70 66	.0005 .00067	355	2.1 2.9	49.0 61.0	2.1 0.8
2A 2B	87	26.5	184	69.0 39.5	0	-192 -163	88 59	.00027 .0009	370	1.2 4.0	69.0 39.5	1.2 4.0
3	91.5	26.5	192	64.0	0	-191	87	.00031	800	3.0	64.0	3.0
4	87	26.5	191	58.7	-6.0	-195	91	.00008	380	0.4	58.7	0.4
6A 6B	96	26.5	159	49.8 36.2	-6.0	-145 -132	41 28	.017 .049	360	73.4 211.7	49.8 36.2	73.4 211.7
7	90	26.5	142	48.5	-9.1	-136	32	.038	800	364.8	48.5	364.8
9	90.8	26.5	196	58.0	-2.5	-192	88	.0001	360	0.4	58.0	0.4
11A 11B	93.4	26.5	185	64.8 33.5	-2.5	-185 -154	81 50	.0002 .0032	360	0.9 13.8	64.8 33.5	0.9 13.8
14	90.8	26.5	194	57.0	0	-187	83	.00017	267	0.5	57.0	0.5
15A 15B	96	26.5	186	41.0 30.2	-6.0	-164 -153	60 49	.0009 .0048	355	3.8 20.4	41.0 30.2	3.8 20.4
									TOTAL	624.0	TOTAL	622

[a]Scan interval of ARSR-60 is 12 s/scan.

[b]This column indicates the pulse count at Trevose with an ARSR-3 installed at Suitland.

[c]P_{RT} = -104.

TABLE 16

PULSE COUNTS FOR THE TREVOSE RADAR WITHOUT
EQUIPMENT #7 AT WILLOW GROVE, PA

Equipment Type	Operating Frequency of the First Channel (MHz)	Pulse Count of the First Channel (pulses/scan)	Operating Frequency of the Second Channel (MHz)	Pulse Count of the Second Channel (pulses/scan)	Pulse Count of the Radar (pulses/scan)
Existing	1300	459	1335	259	718[a]
ARSR-3	1300	452	1335	257	709[a]

[a]This is a total of channels one and two since Trevose is a dual diversity radar.

Pictures taken at Trevose did not reveal the high level of coupling predicted from equipment #7 at Willow Grove, PA. Contact was made with site personnel at Willow Grove and it was determined that in fact the AN/UPS-1C was not radiating. Should #7 be radiating, it would require close coordination with Trevose to prevent degrading interference.

Summary

The sources of interference predicted for Trevose were in fact observed during a site visit. The calculations indicated that two radars are capable of exceeding the interference criteria. Mainbeam-to-sidelobe coupling was found for two bearings which corresponded to the two equipments identified in the calculations. Equipment #7 at Willow Grove is presently deactivated, removing the most serious potential interference source to the Trevose radar. Installation of an ARSR-3 at Suitland should not affect the pulse count at Trevose.

BEDFORD SITE ANALYSIS

Introduction

The Bedford FAA radar site is located in western Virginia close to Roanoke and is a dual usage radar feeding both the Air

Force SAGE system and the FAA's Washington ARTCC. Bedford was chosen for analysis because of the high number (9) of radars with correlated pulses within a 500-statute miles radius. The existing Bedford radar, an AN/FPS-67B, operates on one of two assigned frequencies, 1270 or 1330 MHz. Since this is a 60-MHz separation, the desired ARSR-3 separation of 30 MHz is already met. No new frequency assignment of the Bedford environment was anticipated.

Bedford Electromagnetic Environment

The Bedford environment was compiled primarily from ECAC data files. The resulting environment is shown in TABLES 17 and 18. TABLE 17 lists all L-Band radars within a 200-mile radius of Bedford. TABLE 18 lists only radars with the same PRF in the L-Band within a 500-mile radius of Bedford. The equipments in both tables are ordered by their distance from the Bedford site. Information listed in both tables includes frequency, operating agency and site location, equipment nomenclature, peak transmitter power (P_T), pulse repetition frequency (PRF), pulse width, receiver interference threshold (P_{RT}), receiver scan rate, latitude and longitude, and distance separation. Radars assigned more than one frequency are designated by a number-letter combination. The present Bedford environment does not include any dual-diversity radars. Thus when calculating pulse counts for a particular receiver, the transmitter frequency with the smallest frequency separation from the victim receiver was assumed to be in use. The pulse counts predicted represent the highest possible level of interference. Pulse counts for receivers with two frequencies were calculated twice, once for each operating frequency.

TABLE 17

RADARS WITHIN 200 STATUTE MILES OF BEDFORD

Equipment Number	Operate Frequency (MHz)	Operating Agency and Site	Equipment Nomenclature	P_T (dBm)	PRF (PPS)	Pulse Width (μs)	P_{RT} (dBm)	Scan Rate (RPM)	Latitude (N) Longitude (W) (deg-min-sec)	Distance Separation (Statute Miles)
1A 1B	1270 1330	FAA Bedford, VA	AN/FPS-67B	94.0	360	6.0	-104	5	37-31-02 79-30-39	0
2	1275	Marine Quantico, VA	AN/UPS-1F	91.5	800	4.2	-95	15	38-30-07 77-18-11	138
3A 3B	1317 1341	FAA Benson, NC	ARSR-1D	96.0	370	2.0	-96	3	35-30-30 78-33-30	148
4A 4B	1320 1320	FAA Maiden, NC	ARSR-1D	95.4	365	1.95	-96	6	35-36-42 81-14-24	162
5	1290	Air Force Pope AFB, NC	AN/TPS-44	97.9	267	4.2	-100	15	35-10-00 79-00-00	164
6A 6B	1307 1315	FAA Suitland, MD	ARSR-1E	96.0	355	2.0	-102	6	38-51-14 76-56-22	167
7	1275	Navy Patuxent NAS, MD	AN/TPS-1P	87.0	380	2.0	-94	15	38-17-15 76-24-04	178
8A 8B	1270 1325	Air Force Ft. Meade, MD	AN/FPS-67B	94.0	370	6.0	-104	5	39-06-59 76-43-39	186
9A 9B	1300 1320	FAA Lynch, KY	ARSR-2	96.0	370	2.0	-106	6	36-54-58 82-53-26	190
10A 10B	1275 1335	FAA Cape Charles, VA	AN/FPS-7B	100.0	244	6.0	-100	5	37-08-02 75-57-04	197

TABLE 18

RADARS WITHIN 500 STATUTE MILES OF BEDFORD WITH PRF = 360 PPS

Equipment Number	Operate Frequency (MHz)	Operating Agency and Site	Equipment Nomenclature	P_T (dBm)	PRF (PPS)	Pulse Width (μs)	P_{RT} (dBm)	Scan Rate (RPM)	Latitude (N) Longitude (W) (deg-min-sec)	Distance Separation (Statute Miles)
11	1290	Air Force University Park, PA	AN/MPS-11	90.8	360	3	-102	10	40-48-30 77-52-40	243
12A 12B	1310 1315	Air Force Jamestown, OH	AN/FPS-20U	94.0	360	6	-104	7	39-37-29 83-43-26	269
13	1316	FAA Brecksville, OH	ARSR-1E	96.0	360	2	-96	6	41-18-05 81-41-03	285
14A 14B	1305 1325	FAA Elwood City, NJ	ARSR-2	96.0	360	2	-102	6	39-35-19 74-41-56	296
15A 15B	1260 1330	FAA Benton AFS, PA	AN/FPS-20M	93.4	360	3	-104	5	41-21-26 76-17-36	315
16	1300	FAA Atlanta, GA	ARSR-1E	96.8	360	2	-96	6	33-53-39 84-29-55	375

Most of the radars in the Bedford environment operate continuously, as shown by the percent usages in TABLE 19. Columns 1 and 2 list the equipment numbers and operating agencies. Column 3 lists the percentage of time during the week that the transmitter is actually radiating energy. Columns 4, 5, and 6 list the percentages of the weekday, weeknight, and weekend that the equipment is normally manned or on standby.

TABLE 19

PERCENT USAGE OF RADARS IN THE BEDFORD ENVIRONMENT

Equipment Number	Operating Agency	Transmitter (%)	Weekday (%)	Weeknight (%)	Weekend (%)
1A 1B	FAA	99	100	100	100
2	Marine	100	100	100	100
3A 3B	FAA	99	100	100	100
4	Navy	95	60	10	12
5A 5B	FAA	100	100	100	100
6	Air Force	100	100	100	100
7A 7B	FAA	100	100	100	100
8A 8B	Air Force	95	100	100	100
9A 9B	FAA	95	100	100	100
10A 10B	FAA	99	100	100	100

Equipment #4 at Patuxent NAS is a mobile radar operating within a 20-mile radius of the station. For analysis purposes, #4 was assumed to be fixed at the center of its operating circle. Equipment #4 is the only radar included in the Bedford environment that does not operate close to 100% of the time. Radar #4 was included in the environment, and it was assumed that the radar is operating continuously. This approach was taken in order to determine if an interference problem does exist when #4 is operating.

The frequency of equipment #5 at Pope Air Force Base, NC, was not available during the analysis. An unassigned frequency of 1290 MHz for #5 was assumed.

Three other equipments were identified but not included in the Bedford environment because of their low usage. These same three equipments were deleted from the Suitland environment for identical reasons. They included two radars listed by the Naval Surface Weapons Center at Dahlgren, VA, and one radar listed by the Marine Corps air station at Quantico, VA.

The finalized Bedford environment is shown on the map in FIGURE 9. The equipment numbers assigned to the radars in TABLE 17 are used on the map to show their location. The frequency assignment for the Bedford environment is shown in FIGURE 10. Radars assigned more than one frequency are denoted by a number-letter combination.

Pulse Count and Scope Conditions for Radars Between 0-200 Statute Miles of Bedford

The pulse counts for the present AN/FPS-67B and the future ARSR-3 at Bedford are listed in TABLE 20. In calculating the total pulses received per scan from a transmitter operating on one of two assigned frequencies, the frequency with the smallest separation (Δf) from the

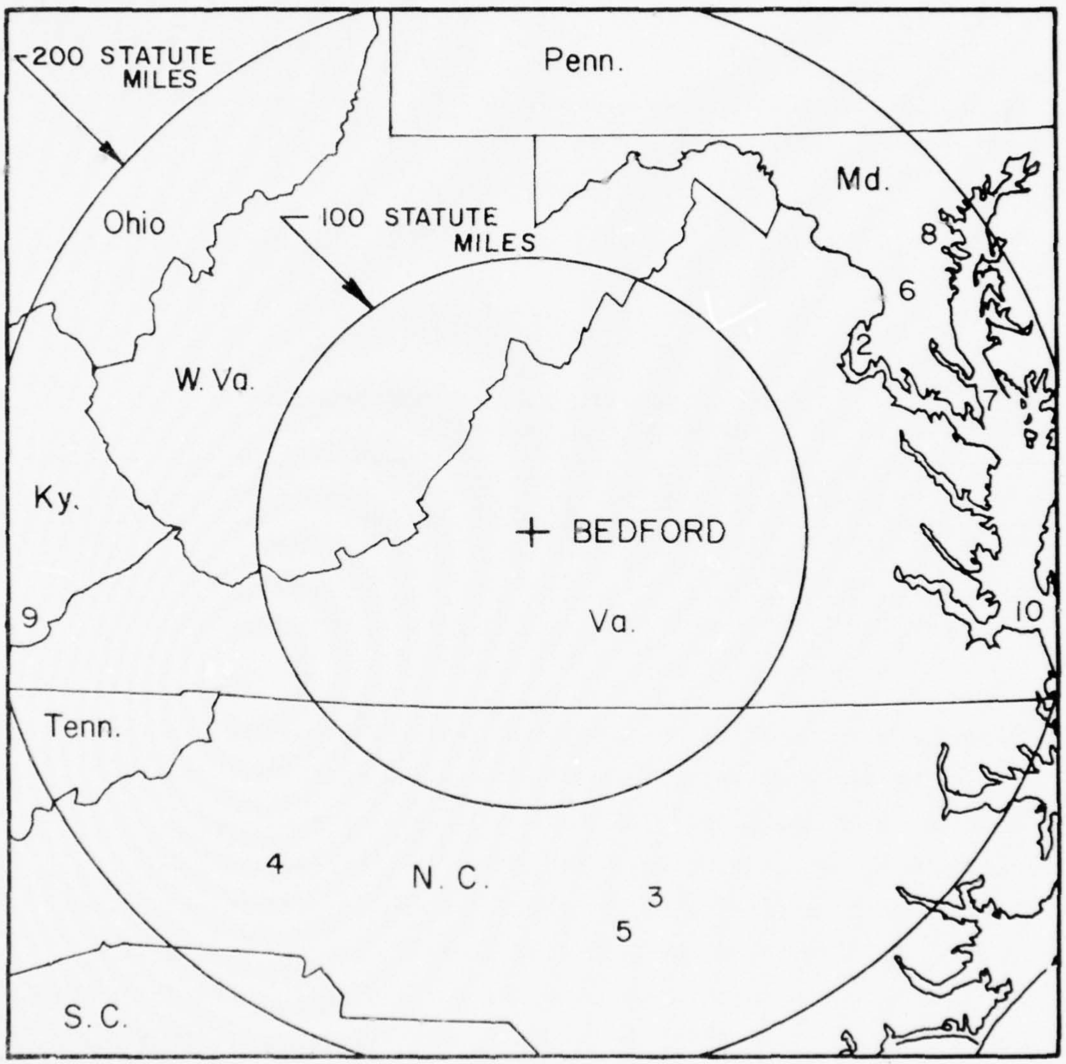


FIGURE 9. LOCATION OF RADARS IN THE BEDFORD ENVIRONMENT.

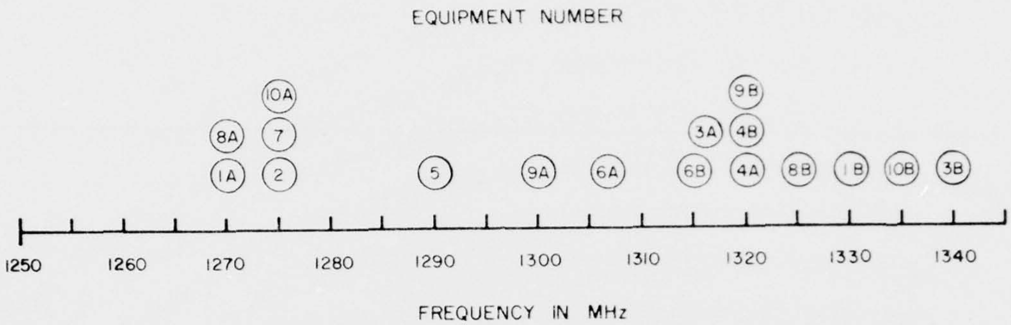


FIGURE 10. EXISTING FREQUENCY ASSIGNMENT IN THE BEDFORD ENVIRONMENT.

TABLE 20

PULSE COUNTS FOR THE EXISTING BEDFORD RADAR AND FOR ARSR-3 CONVERSION

Equipment Type	Operating Frequency of the First Channel (MHz)	Pulse Count of the First Channel (pulses/scan)	Operating Frequency of the Second Channel (MHz)	Pulse Count of the Second Channel (pulses/scan)	Pulse Count of the Radar (pulses/scan)
AN/FPS-67B	1270	166	1330	13	166[a]
ARSR-3	1270	162	1330	18	180

[a]This pulse count only reflects pulses from the first channel since the AN/FPS-67B is not dual diversity.

Bedford radar operating frequency was used. This was accomplished by picking the smallest Δf which corresponded to the smallest $F_{\Delta f}$ in Column 5 of TABLES 21, 22, 23, and 24 and for each radar in the environment. The totals in TABLE 20 are broken down in TABLES 21, 22, 23, and 24 according to the source of the interference. Pulse count calculations for the ARSR-3 at Bedford were made using 1270 and 1330 MHz, the same frequencies already assigned to the AN/FPS-67B. Installation of the ARSR-3 only caused an 8% increase in the Bedford pulse count. This slight increase was due to the dual-diversity operation of the ARSR-3. Since the increase was small and the desired separation of 30 MHz was already met, no attempt was made to change the existing frequency assignment.

TABLE 21

PULSE COUNT PREDICTIONS FOR THE AN/FPS-67B AT BEDFORD, VA, ON CHANNEL A

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	L_p (dB)	$F_{\Delta f}$ (dB)	Pulse Width (μs)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	P_{RT}[b] - $\overline{P}_R$ (dB)	Prob.	PRF (pps)	N/Scan[a] (pulses/scan)
2	91.5	-26.5	189	36.4	4.2	0	-160	56	.001	800	9.6
3A 3B	96	-26.5	196	55.2 61.0	2	-6.0	-188 -194	84 90	.00001 0	370	0
4A 4B	95.4	- -26.5	197	55.7 55.7	1.95	-6.2	-190 -190	86 86	.00001 .00001	365	0 0
5	97.9	-26.5	201	50.5	4.2	0	-180	76	.0032	267	1.0
6A 6B	96	-26.5	202	52.2 50.0	2	-6.0	-191 -194	87 90	.00001 .00001	355	0 0
7	87	-26.5	196	30.0	2	-6.0	-172	68	.006	380	2.7
8A 8B	94	-26.5	205	0 66.5	6	0	-138 -204	34 100	.034 0	370	151.0 0
9A 9B	96	-26.5	207	50.0 56.2	2	-6.0	-194 -200	90 96	0 0	370	0 0
10A 10B	100	-26.5	204	39.5 69.0	6	0	-170 -200	66 96	.00066 0	244	1.9 0
										TOTAL	166

[a]Scan interval of AN/FPS-67B is 12 s/scan.

[b]P_{RT} = -104.

TABLE 22

PULSE COUNT PREDICTIONS FOR THE AN/FPS-67B AT BEDFORD, VA, ON CHANNEL B

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	L_p (dB)	$F_{\Delta f}$ (dB)	Pulse Width (μs)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	$P_{RT}^{b} - \overline{P}_R$ (dB)	Prob.	PRF (pps)	N/Scan[a] (pulses/scan)
2	91.5	-26.5	189	63.7	4.2	0	-188	84	.00001	800	0.1
3A 3B	96	-26.5	196	38.4 36.8	2	-6.0	-171 -169	67 65	.00001 .00069	370	2.7 3.1
4A 4B	95.4	-26.5	197	35.8 35.8	1.95	-6.2	-170 -170	66 66	.00065 .00065	365	2.8 2.8
5	97.9	-26.5	201	59.5	4.2	0	-189	85	.00001	267	0
6A 6B	96	-26.5	202	46.0 40.3	2	-6.0	-184 -179	80 75	.0002 .00037	355	0.9 1.6
7	87	-26.5	196	57.2	2	-6.0	-199	95	0	380	0
8A 8B	94	-26.5	205	67.8 39.5	6	0	-205 -177	201 73	0 .00042	370	0 1.9
9A 9B	96	-26.5	207	49.3 36.0	2	-6.0	-193 -180	89 76	0 .00033	370	0 1.5
10A 10B	100	-26.5	204	66.8 39.5	6	0	-197 -170	93 66	0 .00067	244	0 2.0
										TOTAL	13

[a] Scan interval of AN/FPS-67B is 12 s/scan.

[b] $P_{RT} = -104$.

TABLE 23

PULSE COUNT PREDICTIONS FOR THE ARSR-3 AT BEDFORD, VA, ON CHANNEL A

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	L_p (dB)	$F_{\Delta f}$ (dB)	Pulse Width (μs)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	$P_{RT}^{b} - \overline{P}_R$ (dB)	Prob.	PRF (pps)	N/Scan[a] (pulses/scan)
2	91.5	-26.5	189	36.4	4.2	+6.5	-154	52	.0021	800	20.2
3A 3B	96	-26.5	196	55.2 61.0	2	0	-182 -188	80 86	.00023 0	370	1.0 0
4A 4B	95.4	-26.5	197	55.7 55.7	1.95	0	-184 -184	82 82	.0001 .0001	365	0.4 0.4
5	97.9	-26.5	201	50.5	4.2	+6.5	-174	72	.00047	267	1.5
6A 6B	96	-26.5	202	80.0 75.0	2	0	-212 -208	110 106	0 0	355	0 0
7	87	-26.5	196	30.0	2	0	-166	64	.00074	380	3.4
8A 8B	94	-26.5	205	0 66.5	6	0 +9.6	-138 -194	36 92	.03 0	370	133.2 0
9A 9B	96	-26.5	207	50.0 56.2	2	0	-188 -194	86 92	0 0	370	0
10A 10B	100	-26.5	204	39.5 69.0	6	+9.6	-160 -190	58 38	.00092 0	244	2.7 0
										TOTAL	162

[a]Scan interval of ARSR-3 is 12 s/scan.

[b]$P_{RT} = -102$

TABLE 24

PULSE COUNT PREDICTIONS FOR THE ARSR-3 AT BEDFORD, VA, ON CHANNEL B

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	L_p (dB)	$F_{\Delta f}$ (dB)	Pulse Width (μs)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	$P_{RT}^{b} - \overline{P}_R$ (dB)	Prob.	PRF (pps)	N/Scan[a] (pulses/scan)
2	91.5	-26.5	189	63.7	4.2	+6.5	-181	79	.00023	800	2.2
3A 3B	96	-26.5	196	38.4 36.8	2	0	-165 -163	63 61	.00077 .00081	370	3.4 3.6
4A 4B	95.4	-26.5	197	35.8 35.8	1.95	0	-164	62	.0008	365	3.5
5	97.9	-26.5	201	59.5	4.2	+6.5	-183	81	.0002	267	0.6
6A 6B	96	-26.5	202	56.0 56.0	2	0	-188	87	.00001	355	0 0
7	87	-26.5	196	57.2	2	0	-193	91	0	380	0
8A 8B	94	-26.5	205	67.9 39.5	6	+9.6	-196 -167	94 65	0 .00068	370	0 3.0
9A 9B	96	-26.5	207	49.3 36.0	2	0	-187 -174	85 72	.00001 .00056	370	0 2.5
10A 10B	100	-26.5	204	66.8 39.5	6	+9.6	-188 -160	86 58	.00001 .0009	244	0 2.6
										TOTAL	18

[a]Scan interval of ARSR-3 is 12 s/scan.

[b]$P_{RT} = -102$.

The effect of installing an ARSR-3 at Bedford on the other FAA radars in the environment is summarized in TABLE 25. Column 1 lists the equipment number assigned to the FAA radar in TABLE 17. Column 2 lists the operating frequency. Columns 3 and 4 lists the pulse count for the existing environment and after the ARSR-3 installation. Comparison of Columns 3 and 4 shows little difference in the pulse count after the conversion. Therefore, installation of an ARSR-3 at Bedford will not increase the levels of interference at the other FAA radars in the environment.

The effect of installing an ARSR-3 at Bedford on the military radars in the environment is summarized in TABLE 26. Column 1 lists the equipment number assigned in TABLE 17. Column 2 lists the operating frequencies. Columns 3 and 4 list the pulse count, N-score, and scope condition before and after the ARSR-3 conversion. All military radars would experience a scope condition one both with the AN/FPS-67B and the ARSR-3. The pulse counts of some of the radars actually decreased slightly due to more spectral attenuation of the ARSR-3. All pulse counts were calculated using the present Bedford frequency assignment.

TABLE 25

PULSE COUNTS OF THE FAA RADARS IN THE BEDFORD ENVIRONMENT BEFORE AND AFTER CONVERSION TO THE ARSR-3

Equipment Number	Operating Frequency (MHz)	Pulse Count Due to Existing Environment	Pulse Count With ARSR-3 Operating at 1270 and 1330 MHz
3A	1317	223	216
3B	1341	108	108
4A	1320	192	190
4B	1320	192	190
9A	1300	3	3
9B	1320	180	178
10A	1275	562	562
10B	1335	4	3

TABLE 26

PULSE COUNTS, N-SCORES, AND SCOPE CONDITIONS OF MILITARY RADARS IN THE BEDFORD ENVIRONMENT BEFORE AND AFTER CONVERSION TO THE ARSR-3

Equipment Number	Operating Frequency (MHz)	Pulse Count, N-Score and Scope Condition Due to Existing Environment			Pulse Count, N-Score, and Scope Condition if an ARSR-3 was installed in the Environment		
2	1275	182	.0	(1)	76	.0	(1)
5	1290	11	.0	(1)	11	.0	(1)
7	1275	166	.0	(1)	166	.0	(1)
8A	1270	655	.3	(1)	59	.0	(1)
8B	1325	2378	2.0	(1)	1004	.5	(1)

Radars Between 200-500 Miles with the same PRF

TABLE 18 listed 6 radars with the same PRF as Bedford at distances between 200-500 miles. Five of these radars do not operate on-tune with Bedford and thus have enough frequency separation to preclude interference. Equipment #15B at Benton AFS, PA, does operate on tune with one of the channels at Bedford. When both Bedford and Benton are transmitting on 1330 MHz, the possibility of interference exists as shown in TABLE 27. About 60 pulses per scan are predicted with the AN/FPS-67B and 86 pulses per scan with the ARSR-3 using a median propagation path loss of 221 dB. Fifty percent of the time, 86 pulses per scan would be received with the ARSR-3 installed.

A higher confidence interval was used to calculate the propagation loss for the Benton (#15) to Bedford (#1) path. A path loss of 210 dB would be exceeded 95% of the time. Two hundred and ten dB was used to calculate the pulse counts and resulted in 168 pulses per scan for the AN/FPS-67B and 194 pulses per scan for the ARSR-3 as shown in TABLE 28. These pulse counts could be expected 5% of the time. Since a video integrator or common digitizer is not capable of removing interference of the same PRF, equipment #15B represents a potential interference problem of the above magnitude to Bedford. A simple solution would be to reassign the on-tune frequency (1330 MHz) of either radar. A frequency separation of only 2 MHz almost completely corrects the problem. As shown in TABLE 29, a 2-MHz separation reduces the pulse counts to 4 pulses per scan for the AN/FPS-67B and 9 pulses per scan for the ARSR-3. Also, 2 MHz would not change significantly the pulse counts and N-scores of the other radars in the environment. Although a 2-MHz separation significantly reduced the pulse counts, a somewhat larger separation would actually be required to account for the frequency tolerance of the radars.

TABLE 27

PULSE COUNT PREDICTIONS FOR BEDFORD USING MEDIAN (50%) PATH LOSS

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	$\overline{L}_p$ (dB)	OFR (dB)	Pulse Width (μs)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	$P_{RT} - \overline{P}_R$ (dB)	Prob.	PRF (pps)	N/Scan (pulses per scan)	Type of Environment
15B	93.4	-26.5	221	0	3	-2.50	-156.6	42.6	.014	360	60.5	AN/FPS-67B
15B	93.4	-26.5	221	0	3	0	-154.1	40.1	.02	360	86.4	ARSR-3

TABLE 28

PULSE COUNT PREDICTIONS FOR BEDFORD USING 95% PATH LOSS

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	L_p (dB)	OFR (dB)	Pulse Width (μs)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	$P_{RT} - \overline{P}_R$ (dB)	Prob.	PRF (pps)	N/Scan (pulses per scan)	Type of Environment
15B	93.4	-26.5	210	0	3	-2.50	-145.6	31.6	.039	360	168.5	AN/FPS-67B
15B	93.4	-26.5	210	0	3	0	-143.1	29.1	.045	360	194.4	ARSR-3

TABLE 29

PULSE COUNT PREDICTIONS FOR BEDFORD USING 95% PATH LOSS WITH A 2-MHz FREQUENCY SEPARATION

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	L_p (dB)	OFR (dB)	Pulse Width (μs)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	$P_{RT} - \overline{P}_R$ (dB)	Prob.	PRF (pps)	N/Scan (pulses per scan)	Type of Environment
15B	93.4	-26.5	210	25	3	-2.5	-170.6	56.6	.001	360	4.3	AN/FPS-67B
15B	93.4	-26.5	210	23	3	0	-166.1	52.1	.002	360	8.6	ARSR-3

Summary

Installation of an ARSR-3 at Bedford results in an 8% increase in pulse count. The increase is due to the dual-diversity operation of the ARSR-3. The pulse count predictions were calculated using 1270 and 1330 MHz, the frequencies already assigned to Bedford. Since the increase in pulse count was small, no attempt was made to reassign the frequencies in the Bedford environment for radars within 200 miles.

The effect of the ARSR-3 on the other FAA and military radars within 200 miles of Bedford is negligible. The pulse counts either remained constant or decreased slightly.

A potential interference source was identified at Benton AFS, PA. Equipment #15B at Benton operates on-tune (1330 MHz) and with the same PRF (360 pps) as Bedford. Reassigning one of the on-tune frequencies to achieve a 2-MHz separation can remove the interference problem with minimal effect on the remaining radars in the environment.

ATLANTA SITE ANALYSIS

Introduction

The Atlanta FAA radar site is located northwest of Atlanta, Georgia, on Dobbins AFB. The site was chosen for analysis because of the relatively dense radar environment. Three other radars are within 10 miles of the Atlanta site and a total of 10 radars are within a 200-mile radius. Four closely spaced equipments were expected to cause significant interaction. Siting of an ARSR-3 at this location was completed as an analysis exercise. Installation of an ARSR-3 is not planned as part of the initial phase of the FAA modernization plan.

Atlanta Electromagnetic Environment

The Atlanta environment was compiled primarily from ECAC data files. The environment is shown in TABLES 30 and 31. TABLE 30 lists all L-Band radars within a 200-mile radius of Atlanta and these equipments are shown on the map in FIGURE 11. TABLE 31 lists radars within a 500-mile radius which have the same PRF as the Atlanta radar. The equipments in both tables are ordered by their distance from the Atlanta site. The operating frequencies were obtained by user contact and are listed in the tables with other equipment parameters.

Information on percent usage was obtained for 3 equipments, #2, 3, and 4 which are nearby. Equipment #2 is located several hundred feet away from the Atlanta site and is used 4 or 5 hours per week by a Marine reserve unit. Interference is avoided by use of a synch trigger between the Marine radar and the FAA radar. Even with the trigger, there are some problems with clutter returns. Equipments #3 and #4 which are 10 miles away are used approximately 10 hours per week and one full weekend per month by an Air National Guard unit. These two radars function as part of a training mission. Due to interference between them, they are used one at a time for training.

It was determined that even though #1 and #2 are separated from #3 and #4 by only 10 miles, there is considerable shielding from intervening terrain. There was extensive testing at the time equipments #3 and #4 were installed to check for compatible operation with the FAA radar.

The frequency assignment for the Atlanta environment is shown in FIGURE 12. Radars assigned more than one frequency are denoted by a number-letter combination. The first of the three lines in the figure gives the frequencies used in the existing environment.

TABLE 30

RADARS WITHIN 200 STATUTE MILES OF ATLANTA

Equipment Number	Operate Frequency (MHz)	Operating Agency and Site	Equipment Nomenclature	P_T (dBm)	PRF (PPS)	Pulse Width (μs)	P_{RT} (dBm)	Scan Rate (RPM)	Latitude (N) Longitude (W) (deg-min-sec)	(Statute Miles)
1A 1B	1310 1318	FAA Atlanta, GA	ARSR-1E	96.8	360	2.0	-106	6	33-53-39 084-29-55	0
2	1270	Marine Atlanta, GA	AN/UPS-1B	91.5	360	1.4	-105	6	33-57-00 084-34-00	5
3	1305	Air Force Kennesaw, GA	AN/MPS-11	90.0	355	3.0	-112	6	34-01-11 084-36-15	10
4	1335	Air Force Kennesaw, GA	AN/TPS-44	88.5	800	1.4	-110	6	34-01-11 084-36-15	10
5	1300	Air Force Robins AFB, GA	AN/TPS-44	90.8	267	4.2	-110	15	32-38-12 083-36-00	100
6[a]	1265[b]	Army Redstone Arsenal, AL							34-40-00 086-37-50	133
7	1300	Air Force Alcoa, TN	AN/TPS-44	90.8	633	2.7	-120	20	35-49-10 083-59-50	135
8A 8B	1291 1300	FAA Ramer, AL	ARSR-1D	96.0	350	2.0	-106	6	32-12-38 086-10-01	151
9A 9B	1310 1250	FAA Aiken, SC	AN/FPS-7C	100.0	244	6.0	-110	5	33-45-47 081-40-37	162
10	1285[b]	Air Force Dothan, AL	AN/TPS-44	90.8	267	4.2	-110	15	31-14-00 085-26-00	191

[a]Classified equipment.
[b]Assumed frequency.

TABLE 31

RADARS WITHIN 500 STATUTE MILES OF ATLANTA WITH PRF = 360 PPS

Equipment Number	Operate Frequency (MHz)	Operating Agency and Site	Equipment Nomenclature	P_T (dBm)	PRF (PPS)	Pulse Width (μs)	P_{RT} (dBm)	Scan Rate (RPM)	Latitude (N) Longitude (W) (deg-min-sec)	Distance Separation (Statute Miles)
1A 1B	1310 1318	FAA Atlanta, GA	ARSR-1E	96.8	360	2	-106	6	33-53 39 084-29-55	0
12	1290	Navy Glynco, GA	AN/FPS-37	90.8	360	3	-112	6	31-15-25 081-26-59	254
13A 13B	1320 1318	FAA Moscow, MS	AN/FPS-37A	90.5	360	3	-112	6	32-43-08 088-50-40	263
14	1265	Air Force Tyndall, FL	AN/FPS-64A	94.0	360	6	-114	5	30-04-33 085-36-32	271
15	1318.9	Navy Pensacola, FL	AN/FPS-8	90.0	360	3	-112	6	30-20-58 087-18-43	294
16A 16B	1310 1270	Air Force Jacksonville, FL	AN/FPS-66A	94.0	360	6	-114	5	30-13-17 081-40-58	302
17A 17B	1330 1275	Air Force Keesler, MS	AN/FPS-60	94.0	360	6	-114	5	30-24-30 088-55-00	352
18	1250	Air Force Keesler, MS	AN/FPS-66A	94.0	360	6	-114	10	30-24-13 088-55-09	353
19[a]		Air Force Keesler, MS	AN/FPS-66						30-24-23 088-57-35	354
20A 20B	1270 1330	FAA Bedford, VA	AN/FPS-67B	94.0	360	6	-114	5	37-31-02 079-30-39	375
21A 21B	1315 1310	Air Force Jamestown, OH	AN/FPS-20U	94.0	360	6	-114	7	39-37-29 083-43-26	397
22A 22B	1345 1260	FAA Patrick, FL	AN/FPS-66A	94.0	360	5.4	-114	3	28-12-50 080-35-58	454
23A 23B	1300 1350	FAA St. Louis, MO	ARSR-1E	96.0	360	2.0	-106	6	38-42-04 090-23-26	466

[a]Classified equipment.

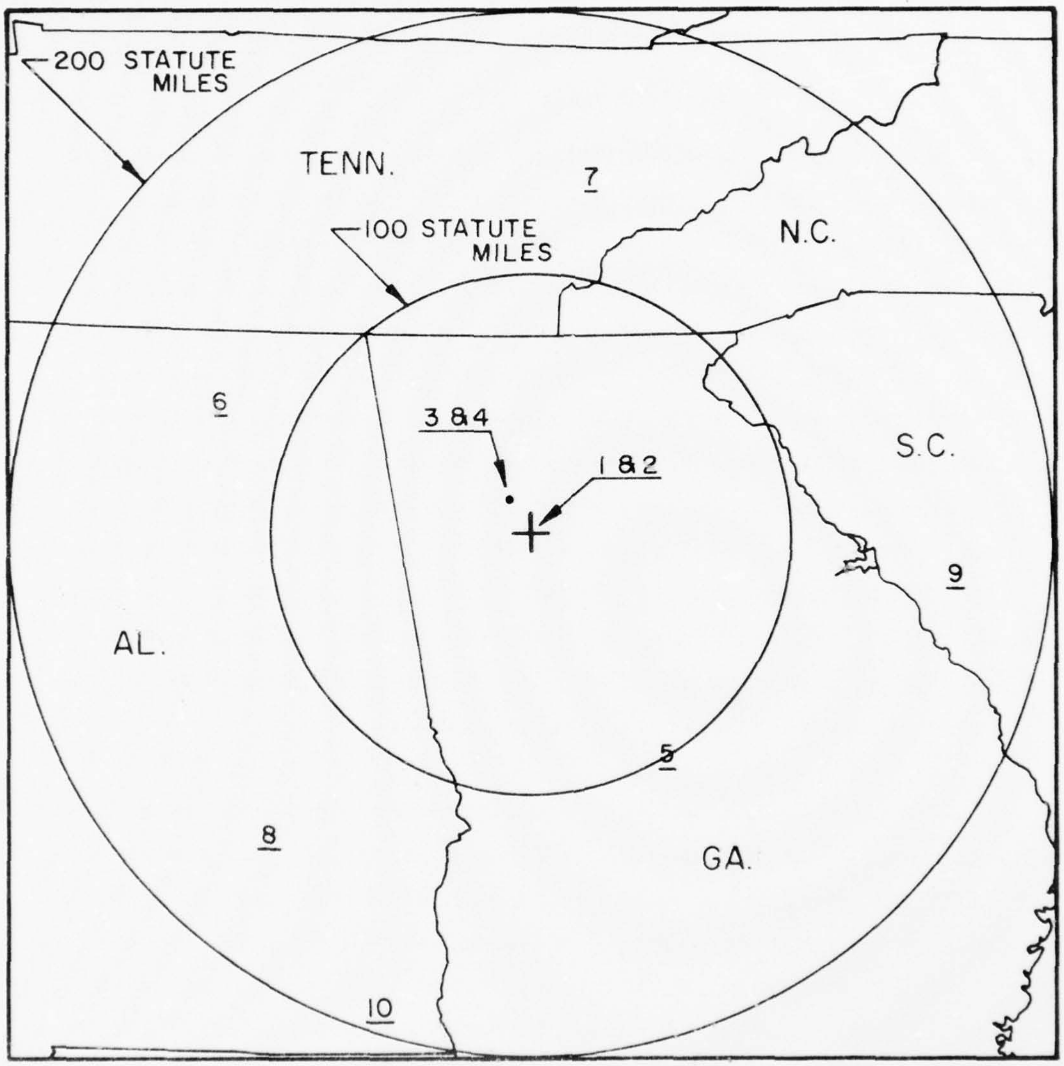


FIGURE 11. LOCATION OF RADARS IN THE ATLANTA ENVIRONMENT.

The next two lines give the new frequencies that were assigned to equipments #1, 2, 3, and 4 for a trial frequency assignment. These will be discussed in the section under pulse count calculations.

Pulse Count and Scope Conditions for Radars Between 0-200 Miles of Atlanta

The pulse count at the Atlanta site was calculated for three frequency assignments. The frequency assignments are shown in FIGURE 12 and the pulse counts are summarized in TABLE 32. The first case is for the currently deployed ARSR-1 with the existing frequency assignment. The detailed calculations for this case are given in TABLES 33 and 34. The second case is for the deployment of an Atlanta ARSR-3 with 30-MHz separation between channels and no other changes to the environment. In the third case, the frequencies of nearby equipments #3 and #9 are also moved to minimize the coupled interference. The results of the ARSR-3 deployment were that the pulse count increased by 18% in one case and decreased by 23% in the last case. This was due to improvements in the frequency assignment that approximately cancelled out the effect of adjacent band interference received by the second radar channel.

The pulse count was also calculated for other FAA radars in the environment. Due to the wide distance spacing, the pulse count was significant at only two other sites both of which share co-channel frequency assignments. The Aiken Radar (#9) is a joint use facility and shares one channel with Atlanta. When both radars are on this channel, a pulse count of 126 pulses per scan was predicted for the Aiken site. The other site is the FAA radar at Ramer, AL. One channel is shared with #5, an AF radar at Robins AFB, that can cause 93 pulses per scan and #7, an Air National Guard radar at Alcoa, TN, which can cause 69 pulses per scan. These can cause a combined pulse count of 157 pulses per scan at the Ramer radar.

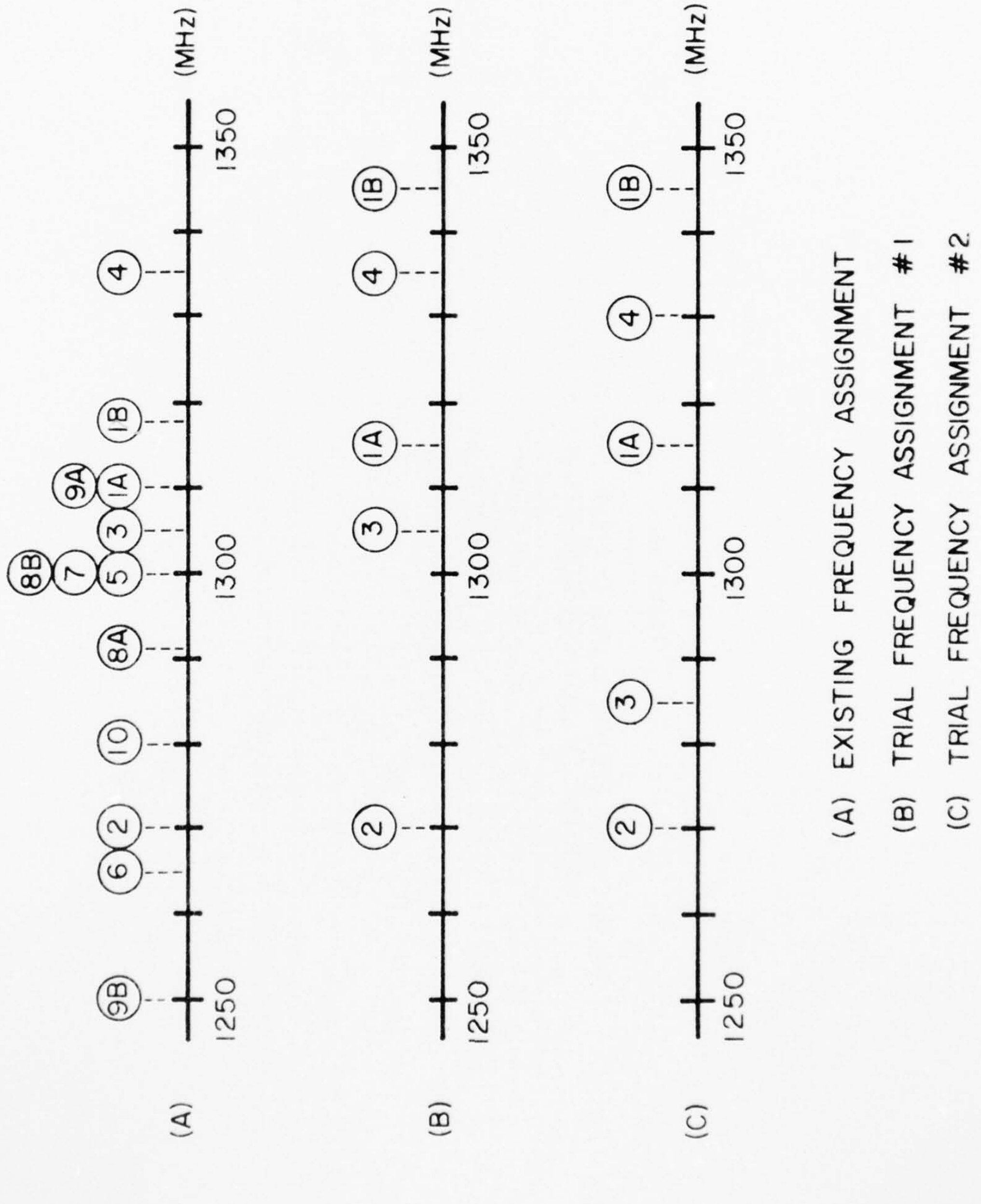


FIGURE 12. FREQUENCY ASSIGNMENT FOR ATLANTA, GA.

TABLE 32

PULSE COUNTS FOR THE EXISTING ATLANTA RADAR AND FOR TWO POSSIBLE FREQUENCY ASSIGNMENTS FOR AN ARSR-3

Equipment Type	Operating Frequency of the First Channel (MHz)	Pulse Count of the First Channel (pulses/scan)	Operating Frequency of the Second Channel (MHz)	Pulse Count of the Second Channel (pulses/scan)	Pulse Count of the Radar (pulses/scan)
ARSR-1	1310	378	1318	177	378[a]
ARSR-3 2nd Assig.	1315	255	1345	192	447 (+18%)
ARSR-3 3rd Assig.	1315	128	1345	160	288 (-23%)

[a]This pulse count only reflects pulses from one channel since the ARSR-1 is not dual diversity.

TABLE 33

CALCULATION OF EXISTING PULSE COUNT FOR ATLANTA RADAR (1310 MHz)

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	L_p (dB)	$F_{\Delta f}$ (dB)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	$P_{RT}{}^a - P_R$ (dBm)	Prob. %	PRF (PPS)	Interference[b] (pulses/scan)
2	91	-26.5	——	50	0	——	——	——	——	c
3	90	-26.5	153	33.5	3.5	-119.5	17.5	7	355	248.5
4	88	-26.5	153	43.8	0	-135.3	33.3	3.5	267	93.5
5	90	-26.5	198	42.5	6	-171	69	<.1	267	0
6	87	-26.5	203	57.2	2.6	-197.1	95.1	0	633	0
7	90	-26.5	204	42.5	6	-177	75	<.1	267	0
8B	96	-26.5	206	36.0	0	-17.5	70.5	<.1	350	0
9A	100	-26.5	207	0	0	-131.5	29.5	5	244	130
10	90	-26.5	210	67.9	6	-208	106	0	267	0
									Pulse Count = 378[d]	

[a] P_{RT} = -102 dBm.

[b] Scan time of the ARSR-1 = 10 s/scan.

[c] Pulses triggered from Atlanta ARSR-1.

[d] Used larger of #3 or #4 since they aren't used simultaneously.

TABLE 34

CALCULATION OF EXISTING PULSE COUNT FOR ATLANTA RADAR (1318 MHz)

Equipment Number	P_T (dBm)	$\overline{G}_T + \overline{G}_R$ (dBi)	L_p (dB)	$F_{\Delta f}$ (dB)	C_{BW} (dB)	$\overline{P}_R$ (dBm)	P_{RT}[a] - P_R (dB)	Prob. %	PRF (pps)	Interference[b] (pulses/scan)
2	91	-26.5	——	52.3	0	——	——	——	——	c
3	90	-26.5	153	41.9	3.5	-127.5	25	5	355	177.5
4	88	-26.5	153	38.8	0	-130	28	5	267	133.5
5	90	-26.5	198	49.1	6	-177.6	76	<.1	267	0
6	87	-26.5	203	59.3	2.6	-199.2	97	0	633	0
7	90	-26.5	204	49.1	6	-183.6	82	0	267	0
8B	96	-26.5	206	42.7	0	-179.2	77	<.1	350	0
9A	100	-26.5	207	43.6	9	-168.1	66	<.1	244	0
10	90	-26.5	210	57.0	6	-197.5	95	0	267	0
									Pulse Count = 177[d]	

[a] P_{RT} = -102 dBm.

[b] Scan time of the ARSR-1 = 10 s/scan.

[c] Pulses triggered from Atlanta ARSR-1.

[d] Used larger of #3 or #4 since they aren't used simultaneously.

For military radars, the existing interfering level was calculated both in terms of pulse count and scope conditions. These calculations are summarized in TABLE 35. The calculations indicate that the only significant interference is to equipments #3 and #4 that receive approximately 160 pulses per scan, which is well within scope Condition 1. As previously stated, this does not include the case where #3 and #9 operate simultaneously since this is not a requirement to fulfill the training missions.

TABLE 35

PULSE COUNT, N-SCORE, AND SCOPE CONDITIONS OF MILITARY RADARS IN THE ATLANTA ENVIRONMENT

Equipment Number	Operating Frequency (MHz)	Frequency Assignment #2		
		Pulse Count	N-Score	Scope Conditions
2	1270	2.3	.0	(1)
3	1305	162	1.0	(1)
4	1335	164	.9	(1)
5	1300	2.2	.0	(1)
6	1265	.0	.0	(1)
7	1300	.2	.0	(1)
10	1285	.0	.0	(1)

Radars Between 200-500 Statute Miles with the Same PRF

Twelve radars between 200-500 miles of Atlanta were identified that had a PRF of 360 pulses per second and could possibly present correlated interference pulses for detection. After obtaining the frequency for the existing ARSR-1 and making a trial frequency assignment for an ARSR-3 considering only local equipments, it was ascertained that all four frequency channels corresponded to a frequency from one of the same PRF radars. The distance separation was 263 miles and 302 miles for the ARSR-1 frequencies. For the ARSR-3 frequencies, the distances were 397 miles and 454 miles. This type of interference was discussed in detail for the Bedford, VA, site analysis where the distance was 315 miles. Approximately the same level of coupling could be expected for these distances. The coupling causes only a low pulse count for the median propagation loss however, it can be significant when calculated for the propagation loss that is achieved 5% of the time. If these levels of coupling are objectionable, there is sufficient spectrum to achieve the small amount of off tuning (1 or 2 MHz) that is required to eliminate the interference.

Summary

Several potential problems were identified. The one collocated radar (equipment #2) uses a synch trigger from the FAA radar to suppress direct coupling. However, it can still couple interference by way of clutter returns. This mechanism was not analyzed but interference effects should be minimal due to the low usage and coordination between FAA and the Reserve Unit radar. The second potential problem is from two equipments that are located 10 miles away. Even considering terrain shielding, these radars can exceed the two interference criteria for normal video. Here the signal processing is required to reduce the interference to an acceptable level.

One co-channel radar (FAA, Aiken, SC) can exceed the more stringent criteria when both Aiken and Atlanta are using the 1310-MHz frequency. This problem is amenable to solution using signal processing or coordinated use of the common channel.

Several equipments were identified between 200 and 500 miles which have the same PRF as the Atlanta radar and whose frequency corresponds to an existing assigned frequency or one used in the trial frequency assignments. This class of problem was analyzed in detail under the Bedford site analysis that indicated that these problems can be solved by a minor shift in frequency.

While this site analysis has shown four situations where interference can occur, it also demonstrates that there are many techniques of frequency management and equipment usage to control the level of interference.

SAN PEDRO HILL SITE ANALYSIS

Introduction

The San Pedro Hill FAA radar site is located on the coast of California just south of Los Angeles. This site is not among these chosen for the initial phase of conversion to ARSR-3's. It was chosen for this analysis because it is a dense, relatively compact environment and should effectively illustrate the advantages of prudent frequency assignment. It is also unique in that, unlike the other FAA radars at the sites analyzed in this report, both channels of the existing ARSR-1 are tuned to the same frequency. A second frequency must, therefore, be determined that could be used for the duplex operation of an ARSR-3.

San Pedro Hill Electromagnetic Environment

Besides the ECAC data files, which included the Western Area Frequency Coordinator files, the FAA Area Frequency Coordinator files were available for the purpose of compiling the San Pedro Hill environment. The equipment records compiled from these sources used to represent the day-to-day environment in which the FAA radar at San Pedro Hill must operate are listed in TABLE 36 and TABLE 37. TABLE 36 lists L-Band radars within 200 statute miles and TABLE 37 lists L-Band radars between 200 and 500 statute miles with correlated pulses. Equipments are listed and assigned numbers according to the distance from the San Pedro Hill site. Also given in TABLE 36 and TABLE 37 is such information as operating frequency, operating agency and radar site, equipment nomenclature, transmitter peak output power, P_T, pulse repetition frequency, PRF, pulse width, receiver interference threshold, P_{RT}, the receiver scan rate, and latitude and longitude. If a radar is capable of using one of two frequencies, the assigned number was listed twice followed by an A or B to denote the dual frequency use. When calculating the scope condition and/or pulse count of a receiver caused by interference from a transmitter that is assigned two frequencies, the frequency most likely to cause interference was assumed to be the one in use. For receivers assigned two frequencies, scope condition and/or pulse count were calculated for both of the assigned frequencies.

TABLE 38 lists the equipments by their assigned numbers and their percent usage. Column 1 gives the percent of time during a week the radar is transmitting. The remainder of the table shows at what time during the week the radar is likely to be transmitting. Columns 2-4 give, respectively, the percent of time the radar is manned during the weekday, during the weeknight and during the weekend.

TABLE 36

RADARS WITHIN 200 STATUTE MILES OF SAN PEDRO

Equipment Number	Operate Frequency (MHz)	Operating Agency and Site	Equipment Nomenclature	P_T (dBm)	PRF (PPS)	Pulse Width (μs)	P_{RT} (dBm)	Scan Rate (RPM)	Latitude (N) Longitude (W) (deg-min-sec)	Distance Separation (Statute Miles)
1	1347	FAA San Pedro, CA	ARSR-1E	96.0	370	2.0	-102	6	33-44-48 118-20-09	0
2	1310	USMC Santa Ana, CA	AN/UPS-1D	91.5	800	1.4	-95	6	33-42-31 117-50-13	28
3A 3B	1255 1300	USN San Clemente Island	AN/FPS-20U	93.4	345	6.0	-104	5	32-53-12 118-27-00	59
4	1295	USN San Nicolas Island	ARSR-1B	96.0	360	2.0	-99	6	33-14-57 119-31-16	76
5A 5B	1300 1310	USAF George AFB	AN/TPS-44	90.8	267	4.2	-100	15	34-33-00 117-23-00	77
6	1277	USN San Diego	AN/SPS-12	87.0	600	1.0	-90	6	32-42-25 117-14-47	95
7A 7B	1270 1332	FAA Boron AFS	AN/FPS-67B	94.0	360	6.0	-104	5	35-04-55 117-34-53	101
8	1342	FAA Mt. Laguna AFS	AN/FPS-7	100.0	241	6.0	-100	5	32-52-33 116-24-51	126
9	On Tune	USMC Twentynine Palms	AN/UPS-1	90.0	800	1.4	-95	6	34-14-28 116-03-54	134
10A 10B	1290 1300	USAF Vandenburg AFB	ARSR-1B	97.0	260	2.0	-99	6	34-35-14 120-35-38	141
11	1337	FAA Paso Robles	ARSR-1E	96.0	280	2.0	-100	5	35-23-44 120-21-12	161
12	1250	USAF Cambria AFS	AN/FPS-7	100.0	241	6.0	-107	5	35-31-21 121-03-46	197

TABLE 37

RADARS BETWEEN 200 AND 500 STATUTE MILES WITH PRF = 370 PP

Equipment Number	Operating Frequency (MHz)	Operating Agency and Site	Equipment Nomenclature	P_T (dBm)	PRF (pps)	Pulse Width (μs)	P_{RT} (dBm)	Scan Rate (RPM)	Latitude (N) Longitude (W) (deg-min-sec)
13	1337 1339	FAA Cedar City, VT	ARSR-2	96.0	370	2.0	-112	6	37-35-36 112-51-44

TABLE 38

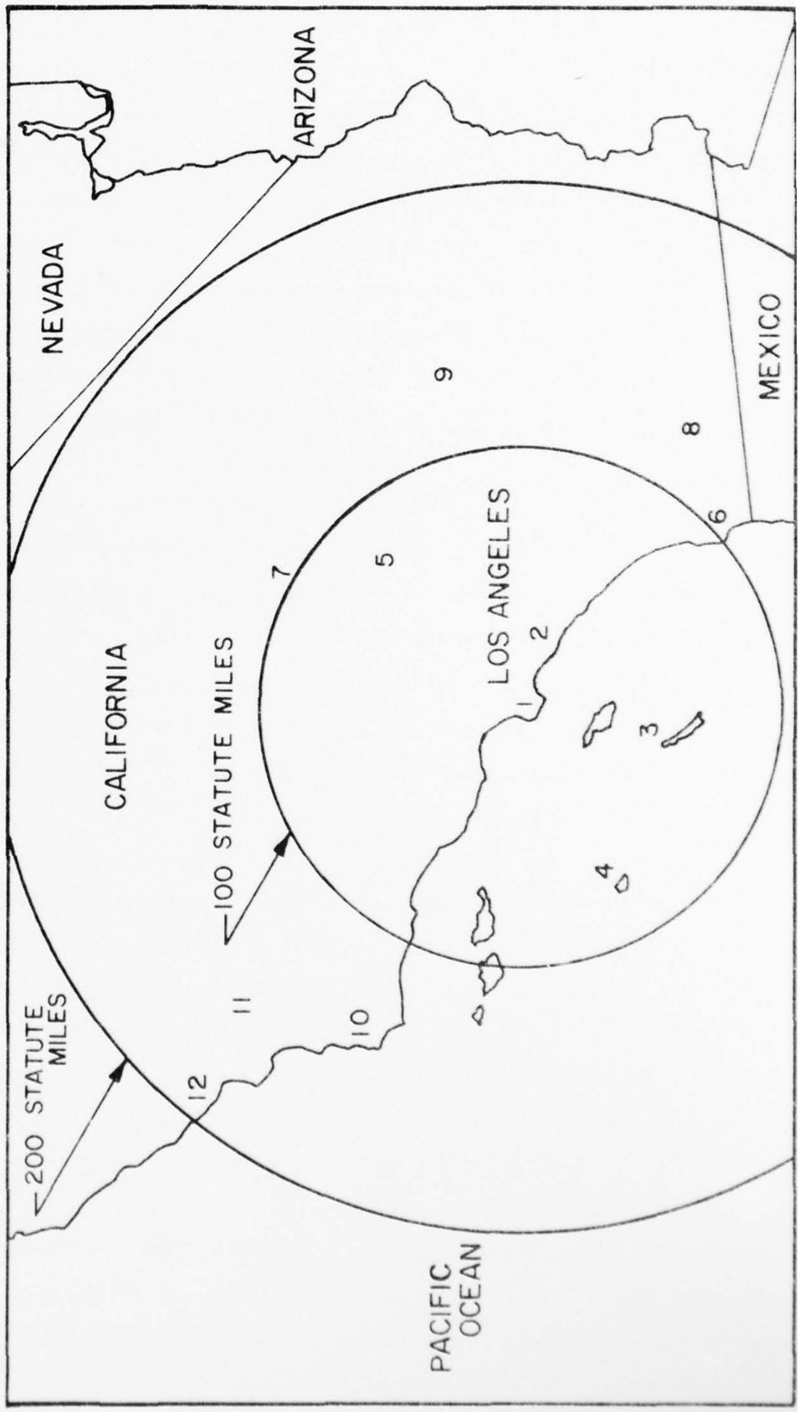
PERCENT USAGE OF RADARS IN THE SAN PEDRO HILL ENVIRONMENT

Equipment Number	Operating Agency	% Time Transmitting	% Time Manned Weekday	% Time Manned Weeknight	% Time Manned Weekend
1	FAA	95	100	100	100
2	USMC	25	100	100	100
3	USN	100	100	100	100
4	USN	95	80	3	—
5	USAF	100	100	100	100
6	USN	50	63	3	—
7	FAA	100	100	100	100
8	FAA	100	100	100	100
9	USMC	30	50	—	—
10	USAF	95	100	100	100
11	FAA	95	100	100	100
12	USAF	99	100	100	100

FIGURE 13 is a map of California with the radar locations de signated by their assigned numbers.

Equipment #2 at the Santa Ana Marine Corps Air Station (MCAS has been included in the analysis even though it is very low usag because of its very close proximity to San Pedro Hill (28 statute miles).

Equipment #7 is capable of diplex operation and it was repor to operate in this mode at times. It was, therefore, assumed for analysis that it would be using both frequencies at the same time


NEVADA
ARIZONA
CALIFORNIA
MEXICO
PACIFIC OCEAN
LOS ANGELES
100 STATUTE MILES
200 STATUTE MILES
1
2
3
4
5
6
7
8
9
10
11
12

Two equipments were reported to be located at the Marine Corps C-E School at Twenty-nine Palms. Both of these equipments are of low usage but were reported in a phone conversation with the operating authority to use any frequency in the 1250-1350 MHz frequency band and thus could operate co-channel with the FAA radars. However, according to OTP rules and regulations, these equipments are allowed to operate in this band on a non-interference basis only. This means they would avoid using frequencies that caused interference to the FAA radars. Therefore for this analysis, one of these equipments was included in the analysis and assigned a frequency of 1305 MHz.

Records of four equipments located at the Marine Corps Base at Camp Pendleton were not included in the analysis because they are tactical equipment used intermittently and for short periods of time. They are not part of the day-to-day environment in which the FAA radar at San Pedro Hill must operate and including them would give an overly pessimistic view of interference. However, their presence should be recognized.

Not included in the analysis are L-Band radars used by U.S. Naval vessels. These radars could present a special problem to the FAA radar at San Pedro Hill due to the presence of Navy ports in the environment (Long Beach and San Diego). They were not included in the analysis for the following reasons. First, the number of shipborne L-Band radars is small and on the decline. The most widely used L-Band radar is being replaced by a radar that operates in another frequency band. Second, shipborne L-Band radars are used for long-range air search operations. This function is needed only when at sea and the radars would be inoperative while in port. Finally, when within 50 nautical miles of port, Navy shipborne L-Band radars are restricted to specific frequency ranges.[7]

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[7]OPNAV 002410.12D, 1968, OP-944F, Serial 005379, p. 94.

AD-A043 726 IIT RESEARCH INST ANNAPOLIS MD F/G 17/9
LONG RANGE RADAR COMPATIBILITY ANALYSIS IN THE 1300-1350 MHZ FR--ETC(U)
JAN 76 D GRIGG, B PIEPER, D LOVE, M KELLY F19628-76-C-0017
UNCLASSIFIED ECAC-PR-75-074 NL

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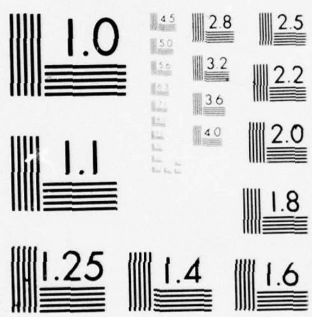


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

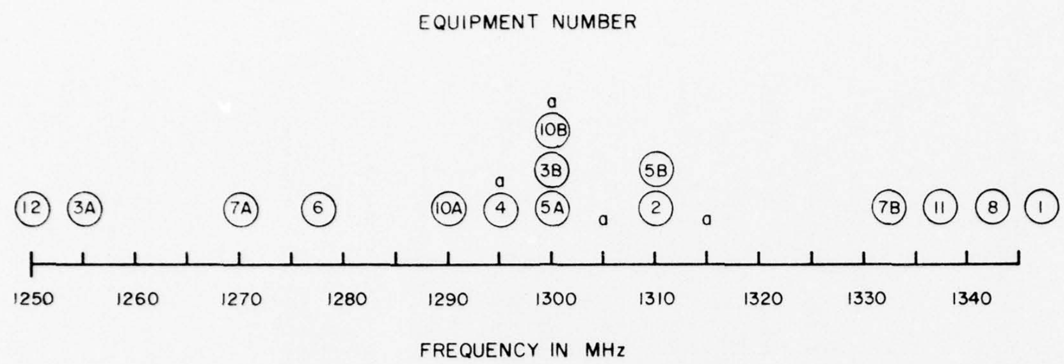
FIGURE 14 is a plot of the 1250-1350 MHz frequency band where the operating frequencies of the different equipment have been noted by their assigned number. Frequencies assigned to Camp Pendleton and used intermittently are footnoted.

Interference to the San Pedro Hill Radar from Radars Located Within 200 Statute Miles

Interference from the Complete Environment. The pulse count calculated for the FAA radar presently installed at San Pedro Hill is given in TABLE 39. Also given in TABLE 39 is the pulse count expected for an ARSR-3 if it were to be installed at San Pedro Hill. Since the existing radar at San Pedro Hill is assigned only one operating frequency, a second had to be chosen for the diplex operation.

A constraint that had to be met when choosing the second frequency was that the two frequencies used by the ARSR-3 had to be at least 20 MHz apart with a desired frequency separation of 30 MHz. The assignment of the second frequency was to meet the above constraints but, in so doing, keep the potential interference as low as possible with as few changes as possible to the existing frequency assignment. In pursuit of this objective, four possible frequency assignments were considered.

The radar presently in use at San Pedro Hill operates at 1347 MHz. Thirty megahertz down from this frequency (the desired frequency separation) is 1317 MHz. Since this frequency is unassigned, it was the first choice for the second operating frequency. The pulse count resulting from this assignment is given in TABLE 39. The pulse count of the ARSR-3 is equal to the sum of the pulse counts of each channel of the radar operating at their respective frequencies. This assignment results in a pulse count much greater than the existing pulse count, an increase of more than 650%.



a - INDICATES FREQUENCIES ASSIGNED TO CAMP PENDLETON

FIGURE 14. EXISTING FREQUENCY ASSIGNMENT IN THE SAN PEDRO HILL ENVIRONMENT.

TABLE 39

PULSE COUNTS FOR THE EXISTING SAN PEDRO RADAR AND FOR ARSR-3 CONVERSION

Equipment Type	Operating Frequency of the First Channel (MHz)	Pulse Count of the First Channel (pulses/scan)	Operating Frequency of the Second Channel (MHz)	Pulse Count of the Second Channel (pulses/scan)	Pulse Count of the Radar (pulses/scan)
ARSR-1E	1347	1105	——	——	1105
ARSR-3	1347	1324	1317	6989	8313
ARSR-3	1347	1324	1327	3197	4521
ARSR-3	1347	1324	1272	1860	3184
ARSR-3[a]	1347	1064	1317	1329	2393

[a]For this assignment the operating frequencies of equipment #2 and #3 were 1275 MHz and 1285 MHz, respectively.

The next choice for the second operating frequency was 1327 MHz. This frequency is unassigned and is twenty megahertz down from 1347 MHz (the minimum frequency separation). This frequency assignment showed some improvment in pulse count over our first frequency choice and, although it is still much higher than the existing pulse count, it is the best that could be achieved by choosing the second operating frequency for the ARSR-3 from presently unassigned frequencies in the 1300-1350 MHz frequency band.

Since the spectrum in the 1300-1350 MHz frequency band is congested and since footnote G12 of the U.S. Government Table of Frequency Allocations permits the operation of government aeronautical radionavigation services in the 1215-1300 MHz frequency band in certain specific cases where necessary and where fully coordinated, the third choice of the second operating frequency was 1272 MHz. As can be seen from TABLE 39, significant improvement has been made in the pulse count, but it is still a good deal greater than the existing pulse count (188% increase).

Up to this point, candidates for the second operating frequency for the ARSR-3 have been chosen from unassigned frequencies. As a final attempt to improve the pulse count, the equipments that would cause interference to the ARSR-3 were reassigned frequencies. From the calculations of pulse count, it was determined that most interference to the ARSR-3 would be caused by equipments #2 and #3B. For the final frequency assignment, the second operating frequency of the ARSR-3 was assigned 1317 MHz (the desired frequency separation) and the operating frequency of equipment #2 was changed to 1275 MHz and equipment #3 was changed to 1285 MHz.

Equipment #3 presently is assigned two frequencies that are widely separated (1255 and 1300 MHz). The second assigned frequency was changed to 1285 MHz because an analysis of the interactions between this radar and the rest of the environment indicates that among

the unassigned frequencies, this one is the least likely to cause interference and it will give equipment #3 the widest possible separation between its assigned frequencies. The frequency of operation of equipment #2 was changed to 1275 MHz; because of the unassigned frequencies, it is the least likely to cause interference.

With this assignment, the pulse count was again significantly improved and represents the best that can be achieved using the desired separation between operating frequencies of the ARSR-3 without major changes to either the frequency assignment or the EMC characteristics of the existing equipment. However, even this assignment exceeded the present level of interference.

Interference From the Environment with Low Usage Equipment Deleted. The pulse counts shown in TABLE 39 are pessimistic because equipment #2 was included in the analysis and it has very low usage. This equipment was dropped and the pulse count recalculated for the four frequency assignments used above. TABLE 40 gives the recalculated pulse counts.

TABLE 40

PULSE COUNTS OF THE EXISTING SAN PEDRO HILL RADAR AND FOR THE ARSR-3 CONVERSION DELETING EQUIPMENT #2

Equipment Type	Operating Frequency of the First Channel (MHz)	Pulse Count of the First Channel (pulses/scan) Excluding Equipment #2	Operating Frequency of the Second Channel (MHz)	Pulse Count of the Second Channel (pulses/scan) Excluding Equipment #2	Pulse Count of the Radar (pulses/scan) Excluding Equipment #2
ARSR-1E	1347	465	——	——	465
ARSR-3	1347	556	1317	845	1401
ARSR-3	1347	556	1327	653	1209
ARSR-3	1347	556	1272	1111	1667
ARSR-3[a]	1347	536	1317	638	1174

[a]For this assignment, the operating frequencies of equipment #3 was 1285 MHz.

As can be seen, there is a great deal of improvement in the pulse count. Operating frequencies of 1272 and 1347 MHz now record the greatest potential interference with an increase of about 260% over the existing pulse count. The possible operating frequencies of 1317 and 1347 MHz and 1327 and 1347 MHz are next in order of potential interference with 1327 and 1347 MHz recording the lesser amount of interference. Operating frequencies of 1317 and 1347 MHz with equipment #3 reassigned to 1285 MHz still record the least amount of potential interference with a 100% increase over the existing pulse count.

Interference To Other Radars

TABLES 41, 42, 43, and 44 record the expected changes in interference to the other radars in the San Pedro Hill environment if an ARSR-3 were installed. TABLE 41 gives the pulse count of the FAA radars in the San Pedro Hill environment. The first column of TABLE 41 gives the equipment number and the second column gives its operating frequency. The third column gives the pulse count due to interference from the existing environment. The expected pulse counts caused by interference from the existing environment with an ARSR-3 replacing the San Pedro Hill radar and using the four possible frequency assignments used above are given respectively in Columns 4, 5, 6, and 7. TABLE 42 gives the pulse counts of these same radars under the same constraints but this time dropping equipment #2.

TABLE 41

PULSE COUNTS OF FAA RADARS IN THE SAN PEDRO HILL ENVIRONMENT
BE[illegible] AND AFTER CONVERSION TO THE ARSR-3

Equipment Number	Operating Frequency (MHz)	Pulse Count Due to Existing Environment	Pulse Count If An ARSR-3 Operating At The Following Frequencies Were Installed In The Environment			
			1317 and 1347 MHz	1327 and 1347 MHz	1272 and 1347 MHz	1317 and 1347 MHz[a]
7A	1270	25	25	25	25	16
7B	1332	14	14	14	17	87
8	1342	385	314	314	311	300
11	1337	303	302	302	302	302

[a]For this assignment, the operating frequencies of Equipments #2 and #3 were 1275 MHz and 1285 MHz, respectively.

TABLE 42

PULSE COUNTS OF FAA RADARS IN THE SAN PEDRO HILL ENVIRONMENT
BEFORE AND AFTER CONVERSION TO THE ARSR-3 DELETING EQUIPMENT #2

Equipment Number	Operating Frequency (MHz)	Pulse Count Due to Existing Environment	Pulse Count If An ARSR-3 Operating At The Following Frequencies Were Installed In The Environment			
			1317 and 1347 MHz	1327 and 1347 MHz	1272 and 1347 MHz	1317 and 1347 MHz[a]
7A	1270	17	17	17	17	15
7B	1332	9	9	9	9	39
8	1342	385	314	314	311	300
11	1337	303	302	302	302	302

[a]For this assignment, the operating frequency of Equipment #3 was 1285 MHz.

TABLE 43

PULSE COUNT OF MILITARY RADARS IN THE SAN PEDRO HILL ENVIRONMENT BEFORE AND AFTER CONVERSION TO THE ARSR-3

Equipment Number	Operating Frequency (MHz)	Pulse Count, N-Score and Scope Condition Due to Existing Environment			Resulting Pulse Count, N-Score and Scope Condition if an ARSR-3 Operating at the Following Frequencies was installed at San Pedro Hill											
					1317 and 1347 MHz			1327 and 1347 MHz			1272 and 1347 MHz			1317 and 1347 MHz[a]		
2	1310	1113	.5	1	1821	1.0	1	812	.3	1	765	.3	1	421	.2	1
3A	1255	281	.1	1	281	.1	1	281	.1	1	281	.1	1	353	.1	1
3B	1300	5448	5.0	2	5387	5.0	2	5305	5.0	2	5305	5.0	2	2946	1.3	1
4	1295	1718	1.3	1	1718	1.3	1	1718	1.3	1	1718	1.3	1	1880	1.5	1
5A	1300	106	.0	1	106	.0	1	106	.0	1	106	.0	1	83	.0	1
5B	1310	826	.5	1	826	.5	1	826	.5	1	826	.5	1	2	.0	1
6	1277.5	81	.0	1	81	.0	1	81	.0	1	101	.0	1	305	.1	1
9	1305	0	.0	1	0	.0	1	0	.0	1	0	.0	1	0	.0	1
10A	1290	162	.0	1	162	.0	1	162	.0	1	162	.0	1	193	.0	1
10B	1300	2111	1.6	1	2111	1.6	1	2111	1.6	1	2111	1.6	1	287	.1	1
12	1250	198	.1	1	198	.1	1	198	.1	1	198	.1	1	198	.1	1

[a]For this assignment, the operating frequencies of Equipments #2 and #2 were 1275 MHz and 1285 MHz, respectively.

TABLE 44

PULSE COUNT OF MILITARY RADARS IN THE SAN PEDRO HILL ENVIRONMENT BEFORE AND AFTER CONVERSION TO THE ARSR-3 DELETING EQUIPMENT #2

Equipment Number	Operating Frequency (MHz)	Pulse Count, N-Score and Scope Condition Due to Existing Environment			Resulting Pulse Count, N-Score and Scope Condition if an ARSR-3 Operating at the Following Frequencies was installed at San Pedro Hill											
					1317 and 1347 MHz			1327 and 1347 MHz			1272 and 1347 MHz			1314 and 1347 MHz[a]		
3A	1255	276	.1	1	216	.1	1	216	.1	1	276	.1	1	348	.1	1
3B	1300	4985	4.7	2	4923	4.7	2	4842	4.7	2	4842	4.7	2	2030	1.2	1
4	1295	1718	1.3	1	1718	1.3	1	1718	1.3	1	1718	1.3	1	1880	1.5	1
5A	1300	104	.0	1	104	.0	1	104	.0	1	104	.0	1	83	.0	1
5B	1310	50	.0	1	50	.0	1	50	.0	1	50	.0	1	2	.0	1
6	1277.5	81	.0	1	81	.0	1	81	.0	1	101	.0	1	203	.1	1
9	1305	0	.0	1	0	.0	1	0	.0	1	0	.0	1	0	.0	1
10A	1290	162	.0	1	162	.0	1	162	.0	1	162	.0	1	162	.0	1
10B	1300	2111	1.6	1	2111	1.6	1	2111	1.6	1	2111	1.6	1	287	.0	1
12	1250	198	.1	1	198	.1	1	198	.1	1	198	.1	1	198	.1	1

[a]For this assignment, the operating frequency of Equipment #3 was 1285 MHz.

As can be seen from TABLES 41 and 42, none of the possible frequency assignments for the ARSR-3 significantly increase interference for any of the other FAA equipments. The 1317-1347 MHz assignment with the operating frequencies of equipments #2 and/or #3 reassigned records the best overall performance.

TABLE 43 gives the present pulse counts, N-scores and scope conditions of military radars in the San Pedro Hill environment and those expected if an ARSR-3 using the frequency assignments used above was introduced into the environment. From this table it can be seen that none of the frequency assignments significantly increase interference (i.e., an increase in scope condition number). The 1317 and 1347 MHz assignment for the ARSR-3 would increase interference to equipment #2; however, equipment #2 is low usage. The 1327 and 1347 MHz assignment would not make any noticeable changes to the pulse counts of any of the equipments. The 1272 and 1347 MHz assignment would decrease interference to equipment #2 but increase interference to equipment #3A. The 1317 and 1347 MHz assignment with the frequencies of equipments #2 and #3B reassigned would significantly reduce interference to equipment #3B (change from Scope Condition 2 to Scope Condition 1), decrease interference to equipments #2, #5B and #10B, and would increase interference to equipments #4 and #10A.

TABLE 44 gives the pulse counts, N-score and scope conditions for these radars dropping equipment #2. Under these conditions, the 1317 and 1347 MHz, 1327 and 1347 MHz and 1272 and 1347 MHz frequency assignments for the ARSR-3 would produce no noticeable change in interference to any of these equipments. The 1317 and 1347 MHz frequency assignment with the frequencies of equipment #2 and #3B reassigned would produce a significant decrease in interference to equipment #3B, decrease interference to equipment #10B, and increase interference to equipment #10A.

Interference to the San Pedro Hill Radar From Radars Located Between 200 and 500 Statute Miles with the same PRF

APPENDIX A shows that L-Band radars separated in distance by more than 200 statute miles are capable of interfering with one another only if their pulses are correlated. Then for distance separations of more than 500 statute miles, interference is highly unlikely. The only radar located between 200 and 500 statute miles of San Pedro Hill is an FAA radar located at Cider City, Utah, which has enough separation between its frequency and the frequencies assigned to the ARSR-3 in this analysis to preclude interference.

San Pedro Hill Site Analysis Summary

If an ARSR-3 were installed at San Pedro Hill, the level of interference presently being experienced by the existing radar could not be achieved unless there were major changes to the existing frequency assignment that could result in unacceptable interference to the rest of the environment. In this analysis, best results, in terms of interference to the ARSR-3, were achieved using frequencies of 1317 and 1347 MHz for the ARSR-3 and reassigning the frequencies of equipment #2 and #3B to 1275 MHz and 1285 MHz respectively. This assignment results in an increase in pulse count of between 100% to 116% depending upon how many low usage equipments included in the analysis are actually operating. This assignment has the desired separation (30 MHz) between the operating frequencies of the ARSR-3. Slightly better results could be achieved if less than the desired separation was used or if equipment #4 was reassigned.

Although this assignment produces the best results, its implementation would also pose the greatest number of problems. First, reassigning the second frequency of equipment #3 would narrow the separation between its two assigned frequencies and may not allow it to perform its function within acceptable levels. Second, equipments

at Camp Pendleton, not included in this analysis because of low usage, are assigned frequencies that may cause interference to an ARSR-3 operating at 1317 MHz and, therefore, would have to be assigned different frequencies (see FIGURE 14). Finally, Naval L-Band radars within 50 nautical miles of Los Angeles are restricted to frequencies which would cause interference to an ARSR-3 at San Pedro Hill operating at 1317 MHz (see Reference 7).

In this analysis, it was ascertained that if an ARSR-3 were installed at San Pedro Hill, it could operate at any of the combination of operating frequencies discussed in this analysis without noticeably increasing interference to most environmental equipments, provided the emission spectrum assumed for the ARSR-3 is realized. With an ARSR-3 in the environment and operating at any of these possible frequency assignments, there would be, at most, two equipments that would have a noticeable increase in interference, but this increase in interference should not degrate the operation of these equipments.

SITE ANALYSIS SUMMARY

A site analysis summary is presented in TABLE 45. It is based on the pulse count calculations for the individual sites. It gives the pulse counts for normal video and does not include processing effects of either a digitizer or integrator. These are treated in a separate section. The first and fifth columns give the average pulse count at the selected sites. The value presented is for a worst-case channel for the existing radar or the sum of both channels for the dual-frequency-diversity radar. These pulse counts allow one to make a judgment on the relative interference levels of the equipments as well as to compare the pulse counts to the pulse count interference criteria. In general, there is approximately twice as much interference for the ARSR-3 due to the extra

TABLE 45

SUMMARY OF INTERFERENCE LEVELS BASED ON NORMAL VIDEO (NO INTEGRATOR OR DIGITIZER)

		Interference At Existing FAA Long Range (1 Channel)				Interference With Dual-Frequency Diversity ARSR-3 (2 Channel) Radar		
		Average Interference Pulse Count (pulse/scan)	Number of Equipment which exceed 1st criterion (64 pulses/scan 5% of time)	Number of Equipment which exceed 2nd criterion (200 pulses/scan 5% of time)	Number of Potential problems due to same PRF same frequency at 200-500 miles	Average Interference Pulse Count (pulses/scan)	Number of Equipment which exceed 1st criterion (64 pulses/scan 5% of time)	Number of Equipment which exceed 2nd criterion (200 pulses/scan 5% of time)
Suitland, MD		636	2	1	None	1414	2	1
Bedford, VA		166	1	1	None for channel A One for channel B	180	1	1
Atlanta, GA		378	2	2	One for channel A One for channel B	288	1	0
San Pedro Hill, CA	a	1105	4	2	None	2393	7	4
	b	465	3	1	None	1174	6	3

[a]Based on worst-cast usage.

[b]Eliminate one low usage equipment.

channel. In one case this was reduced because of an improved frequency assignment, while at San Pedro Hill it is higher since the second assigned channel was more congested than the original channel. When one compares the average pulse counts to the interference criteria, all four sites exceed the 64 pulses per scan criteria for both the original equipment and the dual-frequency-diversity radar. The second less stringent criteria of 200 pulses per scan is exceeded at 3 of the 4 sites for both equipment types.

Columns 2 and 6 give the number of individual equipments in the environment that would exceed the first interference criterion at least 5% of the time. Columns 3 and 7 provide the same equipment count for the higher level criteria. These numbers show that at most of these selected sites, at least one case of interference exists that exceeds the criteria. This holds for both the existing radar and the dual-frequency-diversity radar. Column 4 lists the cases where equipments that have the same PRF as the existing radar were also assigned to the same frequencies. These equipments were all greater than 200 miles away but less than 500 miles. The analysis shows that without the potential for either PRF discrimination or frequency attenuation, these equipments can potentially exceed the interference criteria. Once the problem is recognized, there is sufficient spectrum to accommodate the minor frequency shift required to reduce this interference coupling to an acceptable level.

PROCESSING CIRCUITS

The FAA uses two basic types of processing circuits that use PRF discrimination to differentiate desired target returns from interference. The first type, used for analog presentation, is the delay line integrator. In the delay line integrator, incoming pulses are first passed through a limiter so that a single interference

pulse will not exceed the system threshold. Then, the pulses are fed into the integrator where pulses with the proper PRF are summed (integrated) and fed into the threshold detector. The output threshold is set so as to require a given number of target returns to add before an output occurs.

The other type of processing circuit used by the FAA is a digitizer. In the digitizer, incoming pulses are first passed through a threshold circuit. All target returns, interference, noise, or combinations that exceed the voltage threshold and minimum pulse width criterion will produce a standard response. This is placed in a "sliding window" memory matrix according to range and azimuth information. The system then reads across the azimuth memory cells for a given range and counts the number of responses present. As soon as the count exceeds a preset threshold, a target is declared. Detailed discussions of the delay line integrator and the digitizer are presented in APPENDIXES E and F.

In APPENDIX E, a mathematical model is developed to represent the processing of a radar integrator. An example problem is then solved that shows the processing loss for a typical radar. For a radar with the limiter set 8 dB larger than the average noise level and the gain set to correspond to a false alarm rate of 10^{-5}, the probability of detecting a particular interference pulse is 4.3×10^{-2}. If the radar false alarm rate is 10^{-6}, the interference probability is 7.9×10^{-3}.

The applicable model for a digitizer is given in APPENDIX F. Detection losses are related to both the detection threshold as a function of the number of returns required to declare a target, and the system false alarm rate. An example is given for a single pulse non-synchronous interference where the radar false alarm rate is 10^{-6}

and the detection threshold is 7 returns out of a possible 13 returns. Under these conditions, the probability of one interference pulse being declared a target is 3×10^{-5}.

These two examples show the response of integrator and digitizer processing to non-synchronous interference pulses. Examination of the PRF of environmental equipments has indicated that these false alarm rates represent a reasonable processing loss for all interference due to radars within 200 statute miles of the victim radar. Radars operating on the same PRF as the victim radar have been located only past 200 statute miles where frequency separation is adequate to preclude interference without the processing loss.

When the interference pulse rates from TABLE 44 are mulitplied by the appropriate processing loss, the number of resultant interference pulses being presented on the display scope is less than the interference criteria of 64 pulses per scan and 200 pulses per scan. One exception is the worst case at Los Angeles of 2393 pulses per scan. The 4.3×10^{-2} processing loss results in 102 pulses per scan. A lower limiting level or a lower false alarm rate (e.g., 10^{-6}) could be used to reduce the number of resultant interference pulses per scan to below that of the criterion.

SECTION 3

RESULTS AND CONCLUSIONS

RESULTS

1. A general band study was performed to determine the use and the users of the 1215-1350 MHz frequency band. This study is presented in APPENDIX A.

2. The level of EMC presently existing at each of the four selected FAA LRR sites and their respective L-Band radar environments was evaluated in terms of expected interference pulses. The analysis was repeated assuming the use of a dual-frequency-diversity ARSR-3 radar at the selected site. A summary of the analysis is presented in the subsection of the report entitled, "SITE ANALYSIS SUMMARY."

3. The processing circuits that can be used with the FAA long-range radars are a digitizer or a pulse integrator. These have been analyzed to determine their effect on the calculated levels of interference. The analysis is presented in the subsection of the report entitled, "PROCESSING CIRCUITS." The models developed and used in this report are presented in APPENDIX E and APPENDIX F.

CONCLUSIONS

1. The L-Band radar environment operating within 200 statute miles of the selected LRR radar sites can produce a number of interference pulses that is greater than the criteria at:

a. the present LRR radar or;

b. the replacement ARSR-3 radar; (employing a frequency assignment selected to reduce the number of interference pulses).

This was based on the pulse count without signal processing from an integrator or from a digitizer. When the processing circuits are used, the interference is reduced below the level of the interference criteria.

2. The analysis indicated that in general about twice the number of interference pulses could be expected at the dual-frequency-diversity ARSR-3 radar as from a conventional LRR radar.

3. Use of the total 1250-1350 MHz frequency band for frequency assignments is effective in reducing the number of interference pulses experienced when several radars are located close together.

4. Several problems were identified where the interference source had the same PRF as the victim radar and were not amenable to the processing reduction. These problems can be readily solved by frequency assignment.

5. The FAA LRR radars operating within 200 miles of the selected sites will experience no increase in the number of expected interference pulses caused by the introduction of the ARSR-3 into the environment.

6. For the military radars in the environment allocated one or more channels, there was at least one assigned channel where the interference was low, usually Scope Condition 1 which is defined in APPENDIX D.

APPENDIX A

GENERAL BAND STUDY

INTRODUCTION

A general band study was performed to determine the use and the users of the 1215-1350 MHz frequency band. Rules and regulations governing the use of this band were obtained from the Office of Telecommunications Policy (OTP) Manual of Regulations and Procedures for Frequency Management. The types of equipment operating in the 1215-1350 MHz frequency band, their characteristics and the systems of which they are a part, were identified by examining the ECAC equipment files and library resources.

ALLOCATIONS

The radio spectrum between 1215 MHz and 1350 MHz is divided into two bands. Each of the bands is primarily allocated to the radiolocation or the aeronautical radionavigation service. TABLE A-1 has been extracted from the Office of Telecommunications Policy (OTP) Manual of Regulations and Procedures for Radio Frequency Management and gives both the OTP and the International Telecommunications Union (ITU) allocations for this frequency band with applicable footnotes and definitions given in TABLES A-2 and A-3. A synoptic description of the band usage follows.

1215-1300 MHz Frequency Band

The radiolocation service has been given a primary allocation in the 1215-1300 MHz band by the ITU and by OTP. In the United States and Possessions (US&P), the radiolocation service in the 1215-1300 MHz band is restricted to government agencies.

TABLE A-1

ALLOCATION FOR THE 1215-1350 MHz FREQUENCY BAND

International			United States			
Region 1	Region 2	Region 3	Band	National Provisions	Government Allocation	Non-Government Allocation
1215-1300 MHz RADIOLOCATION Amateur 342 343 344 345			1215-1300 (MHz)	G, NG US34	RADIOLOCATION G12 G55 G56 G111	Amateur
1300-1350 MHz AERONAUTICAL RADIONAVIGATION 346 Radiolocation 347 348			1300-1350 (MHz)	G, NG 346	AERONAUTICAL RADIONAVIGATION Radiolocation G2	AERONAUTICAL RADIONAVIGATION

NOTE: See TABLE A-2 for footnotes and TABLE A-3 for definitions.

TABLE A-2

FOOTNOTES TO TABLE A-1
(Page 1 of 2)

Government (G) Footnotes

(These footnotes, each consisting of the letter "G" followed by one or more digits, denote stipulations applicable only to the Government.)

G2	In the bands 216-225, 420-450, 1300-1400, 2300-2450, 2700-2900, 5650-5925 and 9000-9200 MHz, the Government radiolocation is limited to the military services.
G12	The allocation for the band 1215-1300 MHz does not of itself necessarily preclude Government aeronautical radionavigation operations in this band in certain specific cases where necessary and where fully coordinated.
G55	Authority to operate a joint-use radar (Air Defense/Air Traffic Control) in the band 216-255, 420-450, 1215-1300 and 2300-2500 MHz may be issued to the agency responsible for the technical operation and maintenance of that radar. Despite this dual usage, such radars shall be authorized in the radiolocation service. Present and future requirements for air defense needs shall take precedence over any secondary usage for air traffic control purposes.
G56	Government radiolocation in the bands 1215-1300, 2900-3100, 5350-5650 and 9300-9500 MHz is primarily for the military services; however, limited secondary use is permitted by other Government agencies in support of experimentation and research programs.
G111	In the band 1215-1250 MHz, the frequency 1227.6 MHz with emissions limited to ±12 MHz bandwidth, is also allocated

TABLE A-2

(Page 2 of 2)

G111 to the Radionavigation Satellite Service, for satellite downlink transmissions only. The power flux density at the earth's surface from such transmissions shall not exceed -152 dBW/m^2/4 kHz. The Radionavigation Satellite Service shall not cause harmful interference to the Amateur Service and shall accept any harmful interference that may be caused by the Amateur Service.

US Footnotes

(These footnotes, each consisting of the letters US followed by one or more digits, denote stiplulations applicable to both Government and non-Government stations.)

US34 The only non-Government service permitted in the bands 220-225 MHz, 1215-1300 MHz, 2300-2450 MHz and 5650-5925 MHz is the Amateur Service. The Amateur Service shall not cause harmful interference to the Radiolocation Service.

International Footnotes

(These footnotes come from the Radio Regulations, Geneva, 1959, the Final Acts of the Space EARC, Geneva, 1963, the Final Acts of the Maritime Mobile WARC, Geneva, 1967, or the Final Acts of the Space WARC, Geneva, 1971.)

346 The use of the bands 1300-1350 MHz, 2700-2900 MHz and 9000-9200 MHz by the aeronautical radionavigation service is restricted to ground-based radars and, in the future, to associated airborne transponders which transmit only on frequencies in these bands and only when actuated by radars operating in the same band.

TABLE A-3

DEFINITIONS OF TERMS USED IN TABLE A-1

RADIOLOCATION SERVICE: A radiodetermination service involving the use of radiolocation.
RADIONAVIGATION SERVICE: A radiodetermination service involving the use of radionavigation.
RADIODETERMINATION: The determination of position or the obtaining of information relating to position by means of the propagation of radio waves.
RADIOLOCATION: Radiodetermination used for purposes other than those of radionavigation.
RADIONAVIGATION: Radiodetermination used for the purpose of navigation, including obstruction warning.

The band is also allocated to the radio amateur service on a secondary basis by ITU and OTP regulations.

Although the 1215-1300 MHz frequency band is allocated to the radiolocation service, Government aeronautical radionavigation in this band is permitted in certain specific cases where necessary and where fully coordinated.

Authority to operate joint-use radars (Air Defense/Air Traffic Control) in the band 1215-1300 MHz may be issued to the agency responsible for the tactical operation and maintenance of the radar. Present and future requirements for air defense needs take precedence over any secondary usage for air traffic control.

1300-1350 MHz Frequency Band

ITU and OTP regulations establish the aeronautical radionavigation service as the primary service in the 1300-1350 MHz band. The service

is restricted to ground-based radars and to any associated airborne transponders which transmit only within the band and only when activated by radars operating within the band.

The radiolocation service is also allowed to operate within the band on a secondary basis, according to ITU regulations. In the US&P, the radiolocation service in this band is restricted to the military.

BAND USAGE

Amateur Service

Amateur radio operators are permitted to operate equipment in the 1215-1300 MHz band at stations licensed by the Federal Communications Commission (FCC), provided that the amateur stations do not cause interference to the government radiolocation service. Amateur stations may be operated as portables or mobiles at locations other than the permanent station location.

Amateur stations are limited to 1 kW average power input to the plate circuit of the final stage of the transmitter. Amateur transmitters may use A0, A1, A2, A3, A4, A5, F0, F1, F2, F3, F4, or F5 modulation in the 1215-1300 MHz band. Repeater stations are permitted to operate in the band and are subject to the power and modulation restrictions listed above.

Radiodetermination Services

The 1215-1350 MHz environment is dominated by radars in the radiolocation and aeronautical radionavigation services. Because of band congestion and the safety of life aspects of the aeronautical radionavigation service, a government-wide program requires that land-based radars must coordinate their activities within this band.

Coordination is accomplished through liaison with the appropriate regional Frequency Management Officer (FMO) of the Federal Aviation Administration (FAA). The procedures of this program are contained in Annex D of the OTP Manual of Regulations and Procedures for Frequency Management.

Air Route Traffic Control System. The FAA operates a nationwide network of Air Route Surveillance radars (ARSR's) primarily in the 1300-1350 MHz band. Several joint usage radars (Air Route Surveillance and Air Defense) are operated in the 1215-1300 MHz band. At twenty Air Route Traffic Control (ARTC) centers across the United States, the data received by the ARSR's is processed by computers and displayed on video screens for use by the Air Route Traffic Controllers.

Most of the radars used by FAA for Air Route Surveillance are of the ARSR-1 and ARSR-2 series that were developed to meet FAA specifications. The remaining radars used by FAA are converted military equipments. FAA is presently building a new radar, the ARSR-3, to replace and supplement the present ARSR's.

Navy Shipborne L-Band Radars. Navy shipborne L-Band radars operating in the following coastal areas are restricted to the frequency bands listed in OPNAV 002410.12D.

a. 50 mile radius Norfolk, VA
b. 50 mile radius Boston, MA
c. 50 mile radius San Diego, CA
d. 50 mile radius San Francisco, CA
e. 70 mile radius Los Angeles, CA

416L SAGE System. The US military forces have deployed over 100 L-Band search radars across the contiguous United States. These

radars are used in the 416L Semi-Automatic Ground Environment (SAGE) system to detect air-breathing weapons posing a threat to the United States or Canada. In addition to detecting air-breathing weapons, they track the threat and guide interceptors to the threat.

Under peacetime regulations, the search radars may not operate in the 1300-1350 MHz band unless the 1215-1300 MHz and 1350-1400 MHz bands are too congested to accommodate all of the search radars. It frequently is necessary for a search radar to operate in the 1300-1350 MHz band. Under OTP regulations, these assignments must be fully coordinated with the FAA.

The 416L SAGE System is in a phase-out stage as a result of FAA/USAF agreement NAT-614. The ultimate result will culminate in late CY1978 or early CY1979 in a joint system wherein FAA will own and operate all search radars presently used in the CONUS by both FAA and ADCOM. A total of 113 L-Band radars are presently planned for this ultimate system. ADCOM will utilize the data from 43 of these systems as sensors for their new system (968H).

In addition to the search radars employed by the SAGE system, several of the weapon systems used in conjunction with SAGE also use L-Band radars. These radars will be discussed under each weapon system.

NIKE HERCULES System. In the Continental United States (CONUS), the NIKE HERCULES system was integrated into the SAGE system and was designed to provide continental air defense against attacking aircraft and air-breathing missiles. As of 1 May, 1974, 48 of the remaining 52 NIKE HERCULES sites have been phased out. Four NIKE HERCULES batteries in Florida will remain in operation. However, some of the NIKE HERCULES sites scheduled to be phased out will remain in operation as training facilities.

Each HERCULES battery utilized a variety of radars to perform the search, acquisition, target tracking, target ranging, and missile guidance functions. The Auxiliary Battery Air Defense Radar (ABAR) was used in the NIKE HERCULES System as a backup long range air search radar, and is listed in TABLE A-4.

HAWK System. The HAWK missile system provides mobile defense against low and medium altitude supersonic aircraft and tactical missiles. The HAWK is widely used by the United States Army and friendly forces throughout the world. In the United States, HAWK batteries are deployed around strategic sites and at test ranges such as Fort Bliss and White Sands Missile Range. The HAWK L-Band radar is the AN/MPQ-35 which is listed in TABLE A-4.

Marine Air Command and Control System. The Marine Air Command and Control System (MACCS) provides command and control of Marine Corps aircraft and surface-to-air missile units in air defense operations. This system was formerly named the Marine Tactical Data System (MTDS). MACCS's are deployed in the United States at Marine and Navy bases.

The AN/UPS-1 is a lighweight transportable acquisition radar developed for the MACCS. The AN/UPS-1 and modifications have a tuning range of 1250-1350 MHz.

Forward Area Alerting Radar. The Forward Area Alerting Radar (FAAR) provides low altitude coverage of attacking aircraft. FAAR may be found at Army test ranges presently undergoing evaluation and field testing.

407L Tactical Air Control System. The Tactical Air Control System (TACS) is a mobile, detection and control system for coordinating tactical air operations in the field and coordinating air operations with ground and naval forces.

TABLE A-4

L-BAND RADARS
(Page 1 of 2)

Nomenclature	Frequency (MHz)	Power (kW)	PW (μs)	PRF (Hz)	QTY[a]	Remarks
AN/FPS-7	1250 - 1350	10000	5.8 - 6.2	239 - 247	4	416, FAA
AN/FPS-7 FAA	1250 - 1350	10000	5.8 - 6.2	239 - 247	1	FAA
AN/FPS-7B	1250 - 1350	10000	5.8 - 6.2	239 - 244	2	416L
AN/FPS-7C	1250 - 1350	10000	5.8 - 6.2	239 - 244	4	416L, FAA
AN/FPS-7D	1250 - 1350	10000	5.8 - 6.2	239 - 244	1	416L
AN/FPS-8	1280 - 1350	1200	3.0	360	5	416L, FAA
AN/FPS-19	1220 - 1350	500	6.0	400	12	NORAD
AN/FPS-20A	1250 - 1350	2500	5.4 - 6.6	345 - 375	3	416L, FAA
AN/FPS-20H	1250 - 1350	2500	5.4 - 6.6	345 - 375	1	416L
AN/FPS-20U	1250 - 1350	2500	5.4 - 6.6	345 - 375	16	416L, FAA
AN/FPS-36	1250 - 1350	500	2.0	360 - 400	2	NIKE, HERCULES
AN/FPS-37	1280 - 1350	1200	3.0	360	2	
AN/FPS-37A	1280 - 1350	1200	3.0	360	1	FAA
AN/FPS-64A	1250 - 1350	2500	5.4 - 6.6	345 - 375	2	416L, FAA
AN/FPS-65A	1250 - 1350	2500	5.4 - 6.6	345 - 375	1	416L, Also FPS-20F
AN/FPS-66	1250 - 1250	2500	5.4 - 6.6	345 - 375	2	416L, FAA, Also FPS-20G
AN/FPS-66A	1250 - 1350	2500	5.4 - 6.6	345 - 375	13	416L, FAA, Also FPS-20H
AN/FPS-67B	1250 - 1350	2500	5.4 - 6.6	345 - 375	14	416L, FAA, Also FPS-20M
AN/FPS-69	1250 - 1350	500	2.0	340 - 344	2	NIKE, HERCULES
AN/FPS-75	1250 - 1350	500	2.0	360 - 400	7	
AN/FPS-87A					1	416L, Also FPS-20Q
AN/FPS-91	1250 - 1350	2500	5.4 - 6.6	345 - 375	1	416L, FAA, Outgrowth of FPS-20

TABLE A-4

(Page 2 of 2)

Nomenclature	Frequency (MHz)	Power (kW)	PW (μs)	PRF (Hz)	QTY[a]	Remarks
AN/FPS-94						
AN/FPS-107	1250 - 1350	10000	5.8 - 6.2	239 - 247	15	416L, Improved FPS-7
AN/GSS-1	1220 - 1350	500	2.0	360 - 400	3	
AN/MPS-11	1280 - 1350	1200	3.0	360	11	416L, Mobile FPS-8
AN/SPS-6c	1250 - 1350	150	1 4	570 - 630 285 - 315	3	Navy Schools Ships
AN/SPS-12	1250 - 1350	500	1 4	570 - 630 285 - 315	6	Navy Schools Destroyers
AN/TPQ-31	1250 - 1350	1600	.7 4.2	1600 267	2	Counter Mortar
AN/TPS-1D	1220 - 1350	500	2.0	360 - 400	10	
AN/TPS-1E	1220 - 1350	500	2.0	360 - 400	1	
AN/TPS-1G	1220 - 1350	500	2.0	360 - 400	14	
AN/TPS-44	1250 - 1350	1200	1.4 - 4.2	800 - 267	20	407L
AN/UPS-1	1250 - 1350	1400	1.4 - 4.2	800 - 267	10	MACCS
AN/UPS-1A	1250 - 1350	1400	1.4 - 4.2	800 - 267	1	MACCS
AN/UPS-1B	1250 - 1350	1400	1.4 - 4.2	800 - 267	7	MACCS
AN/UPS-1C	1250 - 1350	1400	1.4 - 4.2	800 - 267	3	MACCS
AN/UPS-1D	1250 - 1350	1400	1.4 - 4.2	800 - 267	2	MACCS
AN/UPS-1F	1250 - 1350	1400	1.4 - 4.2	800 - 267	5	MACCS
ARSR-1A	1280 - 1350	4000	2.0	350 - 370	1	FAA
ARSR-1B	1280 - 1350	4000	2.0	350 - 370	2	FAA
ARSR-1D	1280 - 1350	4000	2.0	350 - 370	12	FAA
ARSR-1E	1280 - 1350	4000	2.0	350 - 370	25	FAA
ARSR-1F	1280 - 1350	4000	2.0	350 - 370	1	FAA
ARSR-2	1280 - 1350	4000	2.0	350 - 370	22	FAA
ARSR-60	1250 - 1350	2500	2.85-3.15	345 - 375	1	FAA
Classified Equipment					106	

[a]Represents quantity of equipments found in E-File.

Radar surveillance of the forward area for the Forward Area Control Post (FACP) is provided by the AN/TPS-44. In addition, FACP can use the radar for air traffic control prior to establishment of the ATRC.

The TACS are located at Tactical Air Command bases.

Counter Mortar and Artillery Locating Radars. L-Band is used by the Marine Corps for counter mortar and artillery locating radars. These radars may be found in the United States at Army and Marine Corps training bases. Radars used for this purpose include the AN/TPQ-31.

Radar Summary. A list of the equipment operating in the 1215-1350 MHz frequency band with their technical characteristics has been compiled and is presented in TABLE A-4. For classified equipments, a summary listing indicated quantity only has been given.

Experimental Services

Non-Government Stations. In the 1215-1400 MHz band, Government services have priority over non-Government services. Licenses for stations in the experimental services have been granted on a non-interference basis by the Federal Communications Commission (FCC). A list of these licenses is contained in TABLE A-5.

Government Stations. OTP has made provisions for government experimental stations that require large and continuously changing frequency resources to operate in many bands without prior authorization of specific frequencies. The provision restricts the stations to experimental operations for short or intermittent periods of time. The operations must be in the immediate vicinity of the station and reasonable measures must be taken before such frequencies are used to insure that harmful interference will not be caused to authorized services.

TABLE A-5

NON-GOVERNMENT LICENSES FOR THE 1250-1350 MHz FREQUENCY BAND AS OF JUNE 1975

Function	Frequency (MHz)	Effective Radiated Power (kW)	Modulation	Location	License
Experimental Development	1215-1300 1350-1400	1.0	P0	Grey Butts Fld, California	KA2XXC
Experimental Development	1215-1300	.0355	A2	Long Beach, California	KM2X0Z
Experimental Development	1250	2.2	P0	Great Neck, New York	KB2XIR
Experimental Development	1260-1264	500.	P0	Valley Forge, Pennsylvania	KC2XBY
Experimental Development	1260,1315 & 1390	3.6	P0	Wayland, Maryland	KE2XAD
Experimental Development	1260-1264	500.	P0	Valley Forge, Pennsylvania	KQ2XRQ
Experimental Development	1295	.6	A0	California	KA2XFM
Experimental Development	1300-1350	2000.	P0	Towson, Maryland	KB2XWC
Experimental Development	1300 & 1350	.00017	A0	Long Beach, California	KB2XET
Experimental Development	1310	.001	P0	Lebanon, New Jersey	KC2XFX
Experimental Development	1333 & 1346	10.	P0	Anne Arundel, Maryland	KC2XEH

Stations operating under this authority may use any frequency in the 1215-1400 MHz band.

Electronic Countermeasures

Military electronic countermeasures (ECM) emissions are designed to cause interference to various portions of the radio spectrum. Such emissions usually require prior coordination with appropriate FAA ARTCC's and North American Air Defense (NORAD) centers. Small scale missions of two aircraft or less do not require prior coordination.

Details of authorized frequency bands and required procedures are specified in IRAC document 8805/1-2.6.2.2. This document is the same as AFR 55-44, AR 105-86, OPNAVINST 3430.9B, MCO 3430.1 and the OTP Manual of Regulations and Procedures for Radio Frequency Management.

APPENDIX B

EQUIPMENT DENSITY STUDY

The purpose of this study was to select specific sites for further analysis. The sites were to be representative of radar sites located in a dense radar environment and were selected on the basis of radar equipment density numbers developed for all of the FAA long-range radar sites.

A list of FAA Air Route Surveillance radar sites was compiled and divided into two categories: those sites scheduled for conversion to ARSR-3's, and other Air Route Surveillance sites. For each site in both categories, the ECAC data files were searched for the records of equipments operating in the 1250-1350 MHz frequency band and located within 170 statute miles. Then for each site, the ECAC data files were searched for the records of equipments operating in the 1250-1350 MHz frequency band, located between 170 and 500 statute miles and using the same pulse repetition frequency (PRF) as the FAA radar at the site under study (synchronous radars).

FIGURE B-1 gives the number of Air Route Surveillance sites with a given number of L-Band radars within 170 statute miles of the site. FIGURE B-2 gives the number of Air Route Surveillance sites with a given number of synchronous L-Band radars between 170 and 500 statute miles of the site.

Using the information contained in these figures, five of the most dense ARSR-3 sites and twelve of the other most dense sites were selected for a preliminary analysis. TABLE B-1 lists these sites along with the number of radars within 170 statute miles and the number of synchronous radars between 170 and 500 statute miles.

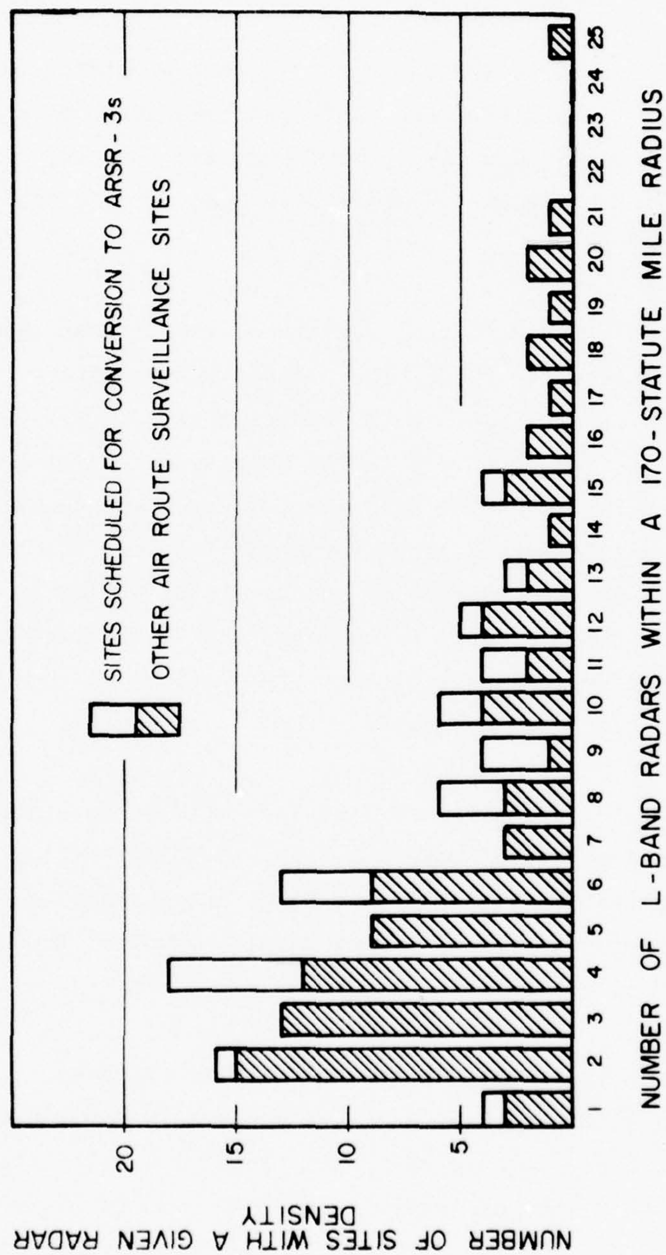


FIGURE B-1. DENSITY OF L-BAND RADARS AROUND ARSR SITES.

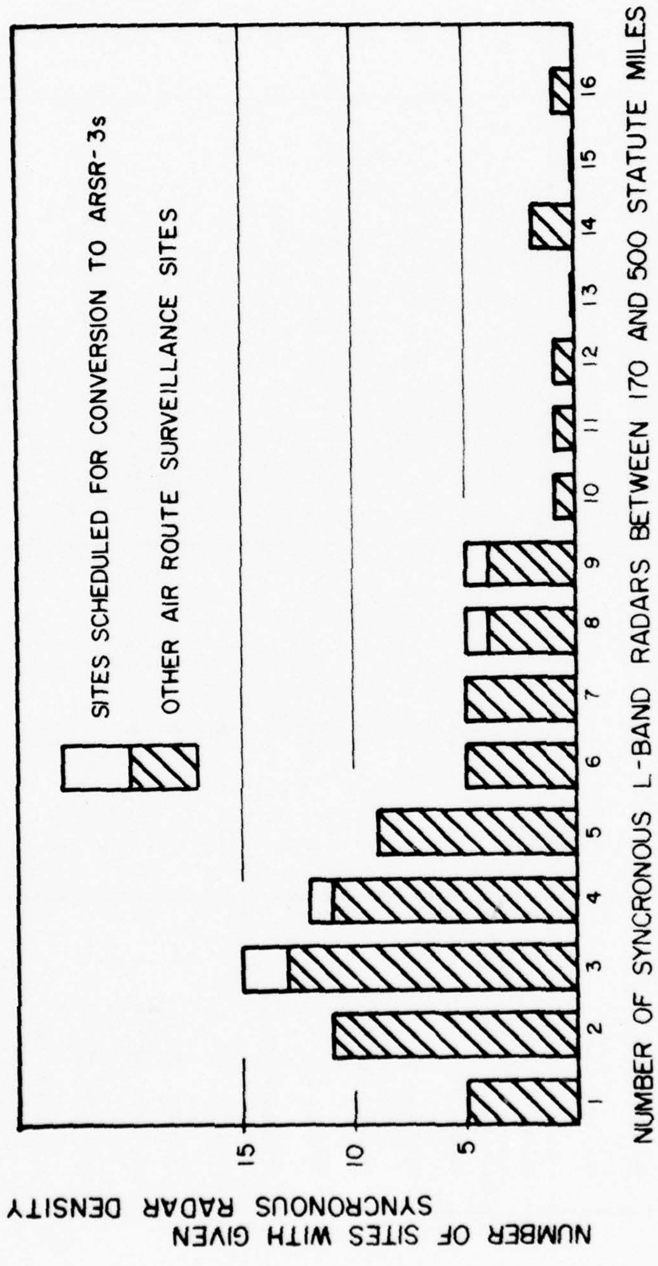


FIGURE B-2. DENSITY OF SYNCHRONOUS L-BAND RADARS AROUND ARSR SITES.

TABLE B-1

HIGH DENSITY AIR ROUTE SURVEILLANCE RADAR SITES

Sites Scheduled for Conversion to ARSR-3	Number of Radars Within 170 Statute Miles	Number of Synchronous Radars Between 170 and 500 Statute Miles	Total
Cape Charles, VA	8	3	11
Chicago, IL	6	8	14
New York City, NY	14	4	18
Suitland, MD[a]	13	3	16
Other Air Route Surveillance Sites			
Aiken, SC	20	3	23
Bedford, VA[a]	9	9	18
Benton, PA	14	10	24
Benson, NC	13	8	21
Cleveland, OH	6	16	22
El Paso, TX	25	1	26
Jedburg, SC	16	8	24
Marietta, GA[a]	10	14	24
Meridian, MS	12	12	24
Red Bluff, CA	10	14	24
San Pedro Hill, CA[a]	17	2	19
Silver City, NM	18	7	25
Trevose, PA[a]	21	3	24

[a]Sites selected for further detailed analysis.

In the preliminary analysis, the records of equipments identified in the distance selects were checked to determine how many of them represented equipments that would be in operation a significant percentage of the time. Operating frequencies of certain key equipments were verified through phone conversations with appropriate authorities. The compactness of the radars in the environment, their function, and use of the available spectrum were noted. Some interference calculations were made. On the basis of this information, four sites with a large potential for interference were selected for in-depth analysis and this selection was coordinated with the FAA. Two of the selected sites were sites scheduled for conversion to ARSR-3's and two were other Air Route Surveillance sites. The four sites selected for analysis are Bedford, VA, Suitland, MD, Atlanta, GA, and San Pedro Hill, CA. The Suitland and San Pedro Hill sites were chosen because of the large number of radars within 170 statute miles. The Bedford and Atlanta sites were chosen because of the large number of synchronous radars between 170 and 500 statute miles. A subsequent decision was made to analyze the Trevose, PA, site. This site is currently using a dual-frequency-diversity radar.

APPENDIX C

MAXIMUM DISTANCE SEPARATION

The purpose of this part of the analysis was to determine the distance beyond which radar transmitters should not cause interference to a particular radar receiver even if tuned to the same frequency. This distance was then used to select equipments for interference analysis. Two maximum distance separations were calculated, the first for equipments using a PRF other than the one used by the victim receiver (non-synchronous radars) and a second for equipments using the same PRF as the victim (synchronous radars). The equation used to calculate the power received from an interfering signal is:

$$\overline{P}_R = P_T + \overline{G}_T + \overline{G}_R - L_p - F_{\Delta f} \qquad \text{(C-1)}$$

where

$\overline{P}_R$ = the mean of the effective peak interference power at the victim receiver, in dBm

P_T = the interfering transmitter peak output power, in dBm

$\overline{G}_T$ = the mean interfering transmitter antenna gain in the direction of the victim receiver, in dBi

$\overline{G}_R$ = the mean victim receiver antenna gain in the direction of the interfering transmitter, in dBi

L_p = the propagation path loss between two isotropic antennas, in dB

$F_{\Delta f}$ = the interfering signal attenuation as a function of the frequency separation between the tuned frequency of the interfering transmitter and the victim receiver, in dB.

To determine the distance beyond which most radar transmitters should not cause interference to Air Route Surveillance Radars, Equation C-1 can be rewritten as follows:

$$L_p = P_T + \overline{G}_T + \overline{G}_R + F_{\Delta f} - \overline{P}_R \qquad \text{(C-2)}$$

where all terms have been defined previously.

Then setting P_R equal to the uncorrelated signal interference threshold of typical Air Route Surveillance radar (-102 dBm) and using typical values for P_T, G_T and G_R (98 dBm, -11 dBi and -11 dBi respectively) and letting $F_{\Delta f} = 0$ (on tune operation),

$$L_p = 178 \text{ dB.}$$

Median values[8] were used in this calculation and give the median (50% confidence level) propagation path loss required for interference-free operation between radars with these characteristics operating on tune. For a cull value, a larger confidence level is desired. The σ of interest is that of P_R. Thus:

$$\sigma^2(P_R) = \sigma^2(P_T) + \sigma^2(G_T) + \sigma^2(G_R) + \sigma^2(L_p) \qquad \text{(C-3)}$$

If it is assumed:

$\sigma(P_T)$ is negligibly small

$\sigma(G_T) = \sigma(G_R) = 9$ dBi[9]

$\sigma(L_p) = 12$ dB[10]

---

[8]Lustgarten, M., *An Approach to the Radar Operational Degradation Problem*, ECAC-TN-71-34, ECAC, Annapolis, MD, July 1971.

[9]Guccione, S., and Ricker III, H., *A Median Gain Model for Rotating Radar Antennas*, ECAC-TN-74-07, ECAC, Annapolis, MD, February 1974.

[10]Lustgarten, M., and Cohen, D., *An Initial EMC Statistical Propagation Loss Model (EPM-73)*, ECAC-TN-73-12, ECAC, Annapolis, MD, March 1973.

then

$$\sigma(P_R) = 17.5 \text{ dB}.$$

The 95% confidence level is 1.64σ, if $\sigma = 17.5$ dB, $1.64\sigma \approx 29$ dB. Equation C-3 is modified by adding 29 dBi, then:

$$L_p\ (95) = 207 \text{ dB}.$$

This provides the required propagation loss for a 95% confidence level. Given this value of L_p, the distance required for the proposed cull may now be estimated by consulting a propagation path loss versus distance graph.

FIGURE C-1 is a distance versus propagation path loss plot for an effective antenna height of 400 feet, obtained using a statistical propagation path-loss model than can be used in situations where accurate location and antenna height data are not available. From FIGURE C-1, it can be seen that the distance a transmitted signal must travel to be attenuated 207 dB is approximately 200 statute miles. This is the cull radius that was used for non-synchronous radars. Interference interactions were then analyzed using the precise values for the terms in Equation C-1 above.

For correlated pulses, the interference threshold of an ARSR is 10-dB smaller than the uncorrelated threshold (-112 dB). Making this substitution into the above equation and leaving the other parameters unchanged, the required path loss is calculated to be 217 dB. The distance correlated pulses would have to travel to be attenuated 217 dB is approximately 400 statute miles. To be conservative, a 500-statute mile cull radius was used to select synchronous radars for in-depth interference analysis.

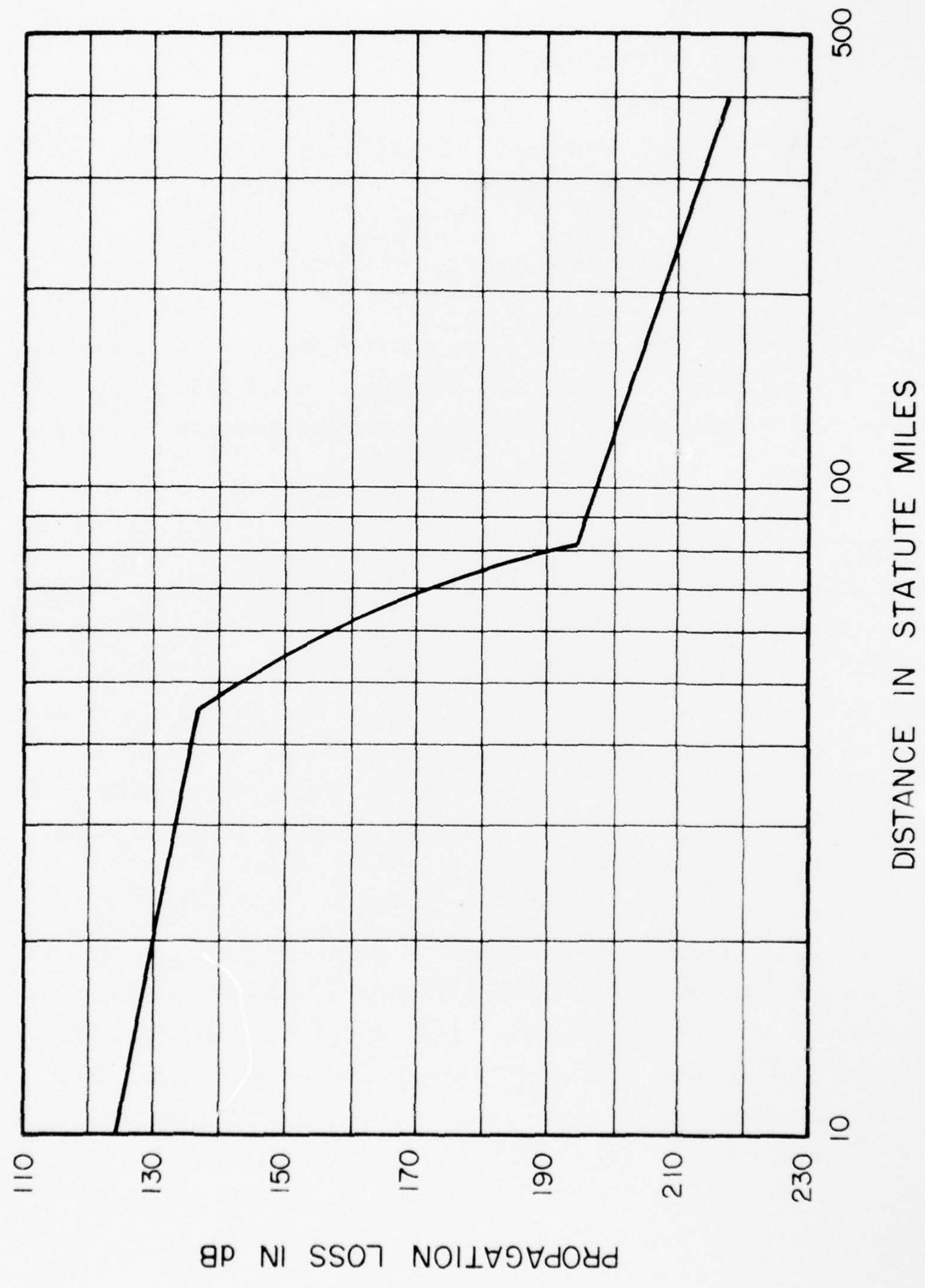
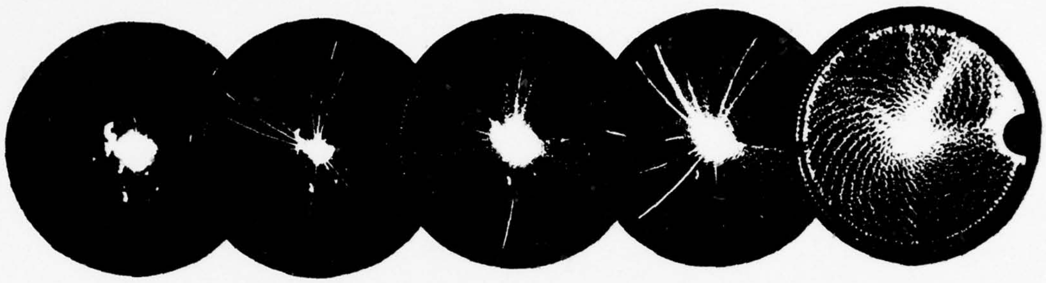


FIGURE C-1. PROPAGATION PATH LOSS PREDICTIONS.

APPENDIX D

CALCULATION OF SCOPE CONDITION



Condition 1 Condition 2 Condition 3 Condition 4 Condition 5

FIGURE D-1. SCOPE CONDITIONS.

FIGURE D-1 shows the five scope conditions used by the Air Force to measure interference. Reference 10 relates each of these scope conditions to an intermediate parameter "N". The scope condition of a receiver is determined by first calculating an N-score for each interfering transmitter using the following equation:

$$N = \sum_{i=1}^{i=k} Q_i \ (P_{Ri} - P_{RT}) \times 10^{-4} \qquad \text{(D-1)}$$

where

Q_i = the number of pulses received per scan of the victim receiver antenna at power level P_{Ri}

P_{Ri} = a discrete power level on the distribution of effective peak interference power, in dBm

P_{RT} = the pulse power necessary to produce interference, in dBm

k = the number of power levels.

Due to receiver saturation, the quantity (P_{Ri} - P_{RT}) will have a maximum value assumed to be 20 dB.

In the calculations of N-scores, the effective peak interference power was assumed to vary as a function of the mutual antenna gain only. Its distribution was approximated by a normal distribution with a 13-dB sigma.

The number of pulses per scan at power level P_{Ri}, Q_i, is equal to the probability of a given pulse being at power level P_{Ri} times the number of pulses transmitted during one scan of the victim receiver antenna.[11] To calculate Q_i, the distribution of effective peak interference power was divided into 4-dB bins. The mid-points of each bin were chosen as the discrete power level, P_{Ri}. Next the standardized variable for each P_{Ri} was calculated using the following equation.

$$X = \frac{P_{Ri} - \overline{P}_R}{\sigma} \qquad \text{(D-2)}$$

where $\overline{P}_R$ was calculated using Equation 1.

Using the standardized variable, the probability of a pulse having a power level greater than or equal to P_{Ri} was located in the table of values of the cumulative distribution function of a standardized random variable provided in standard mathematical tables.[12] Finally, the probability of a pulse having a power level that falls in the bin P_{Ri} - 2 dB to P_{Ri} + 2 dB was found by subtracting the probability of a pulse having a power level greater than or equal to the bin power level, P_{Ri} from the probability of a pulse having a power level greater than or equal to the next higher bin power level $P_{Ri} + 1$. The value of Q_i for this bin was then determined by multiplying the probability

[11]Katz, L., *PPI Interference Predictions*, IEEE Transactions on Electromagnetic Compatibility, June 1965.

[12]*Standard Mathematical Tables*, The Chemical Rubber Co., Cleveland, Ohio, 1970.

of a pulse having a power level between P_{Ri} - 2 dB and P_{Ri} + 2 dB times the number of pulses transmitted per scan of the victim receiver antenna.

Once the N-scores for each interfering transmitter were calculated, they were totaled and the scope condition determined by using the relationship between the total N-score and the scope condition given in TABLE D-1.

TABLE D-1

RELATIONSHIP BETWEEN N SCORE AND SCOPE CONDITION

N Number Range	Scope Condition
0 - 3.7	1
3.8 - 9.4	2
9.5 - 14.7	3
14.8 - 23.2	4
> 23.3	5

A sample calculation of the N score for a particular receiver and transmitter interaction in the San Pedro Hill environment is provided in TABLE D-2. In this table, column 1 is the discrete level, P_{Ri}, on the distribution of effective peak interference power. Column 2 gives the standardized variable for each P_{Ri}. Column 3 gives the probability of a pulse having a power level greater than or equal to P_{Ri}. Column 4 gives the probability of a pulse having a power level between P_{Ri} - 2 dB and P_{Ri} + 2 dB. Column 5 gives Q_i, the number of pulses received per scan of the victim receiver antenna at a power level between P_{Ri} - 2 dB and P_{Ri} + 2 dB. Columns 6 and 7 are self explanatory. At the bottom of the table is the N score of this particular receiver transmitter interaction.

TABLE D-2

CALCULATION OF THE N-SCORE FOR INTERFERENCE FROM TRANSMITTER #10B TO RECEIVER #3D

P_{Ri} (dBm)	$x = \frac{P_{Ri} - \bar{P}_R}{\sigma}$ [a]	Cummulative Probability	Probability	Qi [b] (Pulses/Scan)	$P_{Ri} - P_{RT}$ [c] (dBm)	$Qi\ P_{Ri} - P_{RT}$
-104	-.77	.7794	.1022	319	0	0
-100	-.46	.6772	.1176	367	4	1468
-96	-.15	.5596	.0695	186	8	1488
-94	0	.5000	.0596	186	10	1860
-92	.15	.4404	.1176	367	12	4404
-88	.46	.3228	.1022	319	16	5104
-84	.77	.2206	.0805	251	20	5020
-80	1.08	.1401	.0563	176	20	3520
-76	1.38	.0838	.0838	119	20	2380
-72	1.69	.0455	.0228	71	20	1420
-68	2.00	.0227	.0123	38	20	760
-64	2.31	.0104	.0060	20	20	400
-60	2.62	.0044	.0027	8	20	160
-56	2.92	.0017	.0011	3	20	60
-52	3.23	.0006	.0004	1	20	20
-48	3.54	.0002				

$N = \sum_i Qi \left[P_{Ri} - P_{RT}\right] \times 10^{-4} = 2.80$

[a] $\bar{P}_R$ for transmitter #5A = -94.0 dBm.

[b] Scan Rate Radar #3B = 12 s/scan, PRF transmitter #10B = 267 pps.

[c] P_{RT} for receiver #3B = -104 dBm.

TABLE D-3 gives the N-scores for interference from all the transmitters in the environment to this receiver, the total N-score and the predicted scope condition.

TABLE D-3

N-SCORES OF INTERFERENCE FROM THE ENVIRONMENT TO RECEIVER #3D

Transmitter Number	1	2	4	5A	6	7A	7B	8	9	10B	11	12
N-Score	.05	.16	2.00	0	0	0	0	0	0	2.80	0	0
Total N Score = 5.01 Predicted Scope Condition = Scope Condition 2												

APPENDIX E

RADAR PULSE INTEGRATOR EFFECTS ON NON-MTI VIDEO IN THE PRESENCE OF INTERFERENCE

RADAR INTERFERENCE FUNDAMENTALS

Radar Target

The radar return signal from a point target consists of a series of pulses generated as the beam scans past the target, all separated in time by the radar pulse repetition time. The number of returns (M) will depend upon the radar antenna beamwidth (BW), the rate of antenna rotation (RPM), the radar pulse repetition rate (PRF), and the target characteristics. Equation E-1 determines the number of returns expected from a point target.[13]

$$M = \frac{PRF \times BW}{6 \times RPM} \tag{E-1}$$

where all terms have been defined previously.

The antenna beamwidth (BW) used in determining M is usually taken at the -3 dB points on the antenna gain pattern. For strong signals, many more pulses will be available in the receiver from the lower gain portions of the mainbeam (e.g., the -10 dB beamwidth is approximately 1.7 times the 3-dB beamwidth). However, for weak signals, returns from outside the 3-dB beamwidth are not expected to contribute significantly to the display of the target since they will be below the receiver noise.

[13] *Radar Data Acquisition Subsystem Theory*, FAA Manual FR-605-1, January 1974.

This train of pulses is displayed on a PPI in adjacent azimuth sectors at a fixed distance. The individual returns can scarcely be resolved and the target appears as an elongated blip that allows it to be distinguished from the random noise blips that appear on the scope.

Radar Noise

Radar receiver noise, as in most telecommunication systems, is the limiting factor in determining the sensitivity of the system. The characteristics of the system noise are well defined statistically. The noise signals consists of continuous random variations of amplitude and phase. The amount of noise that is displayed on the scope or fed to an automatic detection device is controlled by setting a voltage threshold that must be exceeded before the signal will be passed on. The threshold is usually expressed as the ratio of the threshold voltage to the RMS noise voltage. The setting of the threshold will determine the probability that a noise pulse will be detected. The mechanics of establishing this threshold vary from radar to radar. In automatic detection systems, precision electronics circuits are used to establish well-controlled false alarm rates. In manual radars, which feed PPI displays directly, the circuitry often consists of an adjustable gain amplifier to control the amplitude of the signal relative to the sensitivity of the phosphor in the PPI.

In the latter case, the actual level to which the threshold is set for optimum performance will depend on the individual. TABLE E-1 is extracted from *Radar Systems Analysis*[14] and presents a range of threshold settings along with the probability that the threshold will be exceeded by noise.

[14]Barton, *Radar Systems Analysis*, Prentice Hall, New York, NY.

TABLE E-1

FALSE ALARM PROBABILITY (P_n) VERSUS THRESHOLD SETTING

P_n	Normalized mean square threshold power $E_t^2/2\Psi_o$ ln $(1/P_n)$ (watts)	Normalized peak threshold voltage $E_t/\sqrt{\Psi_o}$ [a] $= \sqrt{2 \ln (1/P_n)}$ (volts)
1.0	0.0	0.0
0.5	0.69	1.17
0.2	1.61	1.79
0.1	2.30	2.15
0.05	2.99	2.45
0.02	3.91	2.80
0.01	4.61	3.04
0.005	5.30	3.26
0.002	6.22	3.49
0.001	6.91	3.71
0.0005	7.60	3.90
0.0002	8.52	4.13
0.0001	9.21	4.29
10-5	11.5	4.80
10-6	13.8	5.25
10-7	16.1	5.69
10-8	18.4	6.07
10-9	20.7	6.43
10-10	23.0	6.80
10-11	25.3	7.11
10-12	27.6	7.43
10-13	29.9	7.73
10-14	32.2	8.01
10-15	34.5	8.31
10-16	36.8	8.57

[a] $\sqrt{\Psi_o}$ = RMS noise voltage.

The establishment of the operating threshold will determine the minimum detectable signal (MDS) level and a trade-off must be made between the maximum number of noise signals which can be tolerated and minimum detectable signal needed by the system.

Weak radar returns that are below the threshold level will add with the noise and have a probability of detection that is dependent upon the statistical distribution of the noise. Analysis of this interaction yields a probability of detection for the desired target returns and allows for optimum selection of the threshold relative to the radar mission.

Reference 12 indicates that the nature of the FAA mission is such that the emphasis is upon enhancement of the MDS at the expense of accepting the additional noise whereas the early warning radars operated by the USAF emphasize the suppression of false targets. This fact will be taken into consideration when assessing the effectiveness of integration against interference.

Radar Interference

When a radar receives signals from another radar, the manifestation of the interference on the scope will depend upon the signal intensity, the PRF of the interfering signal, and the speed of antenna rotation.

When considering two rotating radar antennas, the range of possible antenna coupling values is very large, 100 dB or more. The peak signal intensity and the relative rotating speeds of the antennas will determine how much of the scope is interfered with and its distribution in time. The PRF will determine the appearance of the interference when it is present.

When radar interference is present, it will usually have peak intensities that exceed the dynamic range of the PPI and cause blossoming of the scope, greatly increasing the degradation caused by the interference. For this reason, most radars are equipped with a video limiting circuit. This circuit keeps all signals desired or undesired below a certain level regardless of the amplitude of the input.

The PRF of the interfering signal will determine how it is displayed on the PPI. If the interfering signal PRF is equal to or is a harmonic of the PRF of the desired signal, the interference will appear as a ring or rings of arcs on the scope at fixed range. If the PRF's differ by as little as 1 pps, the interference will then appear as a series of spirals either increasing or decreasing in range from pulse to pulse.

INTEGRATION TECHNIQUES

Basic Integrator

The combination of human operator and scope actually function as an integrator. The operator views the sequence of target returns amid the background of noise and possibly interference and identifies it as a target; the target pulses add up, the noise does not. The problem with the interference and high noise levels is that they can mask a desired signal. In addition, both interference and noise can cause operator fatigue and lower his proficiency. With automatic detection devices, some method must be devised to perform this integration if the MDS of the radar is to be kept within reasonable bounds. All the commonly used integration techniques are based upon the characteristics of a sequence of desired return pulses that are within a fixed range and azimuth "window." These devices, in effect, require that, before a signal is passed on for display or processing, it must provide (H) constant range returns out of (M) adjacent azimuth windows.

FAA Integration Techniques

The FAA uses two basic integrator types, one for automatic detection (e.g., the Common Digitizer) that uses double threshold digital detection, the other, for analog presentation, is the delay line integrator. The Common Digitizer will be discussed in APPENDIX F.

The basic delay line integrator is depicted in FIGURE E-1. The system consists of a limiter, an adder, a feed-back loop with a delay equal to the time between transmitter pulses and an output threshold. The overall gain, K, of the feed-back loop must be less than unity to prevent oscillations. Values of K range from 0.8 to 0.9 and should be optimized for the expected number of target pulses. The input limit level and output threshold are normally adjustable and can be set up for a number of operating conditions. These adjustments will be discussed in more detail later.

The sequence of action of the integrator on a string of desired target returns is presented in TABLE E-2. The first pulse, S_1, is fed through the adder to the threshold detector and through the feed-back loop. The component fed through the feed-back loop arrives back at the adder coincident with S_2 and of amplitude, KS_1. The sum of these two signals is fed to the threshold and the feed-back loop. The recirculated signal now arrives at the adder coincident with S_3 and its amplitude is number $S_2K + S_1K^2$. This process continues until the beam has swept past the target. The output signal then decays as the signal continues to recirculate through the feed-back loop with no desired input to add with. At some point in the build-up of the signal, the output threshold is exceeded and the target is passed on to the display. The target will continue to be displayed until the signal has decayed to below the threshold level. This delayed build-up and decay introduces a slight azimuth error. In addition, weak signals

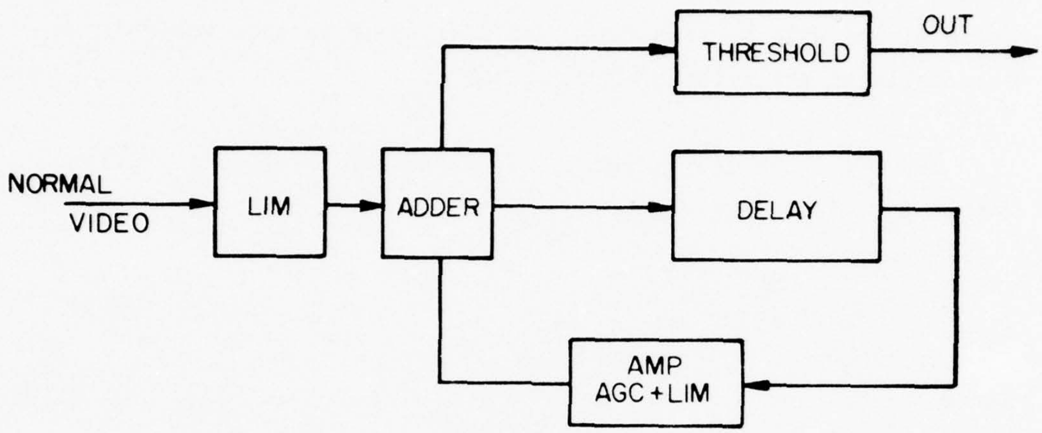


FIGURE E-1. DELAY LINE AMPLIFIER.

TABLE E-2

SEQUENCE OF ACTION OF AN INTEGRATOR ON A STRING OF DESIRED TARGET RETURNS

Number of Pulses Integrated	Resultant Signal Sent to the Threshold Detector and Feed-Back Loop
1	S_1
2	$S_2 + K S_1$
3	$S_3 + K S_2 + K^2 S_1$
4	$S_4 + K S_3 + K^2 S_2 + K^3 S_1$
.	
.	
.	
n	$S_n + KS_{n-1} + K^2 S_{n-2} + \ldots K^{n-1} S_1$

might produce an output equivalent to a single pulse return rather than the typical azimuthal smear on the scope. This is not considered serious. As will be seen later, most of these targets wouldn't be detectable at all without the integrator.

The effect of the integrator is described by the integration factor B_M. This is given by:

$$B_M = \sum_{1}^{M} K^{(n-1)} \tag{E-2}$$

where

n = number of pulses integrated

K = feedback gain

B = integration factor

M = maximum number of pulses that can be integrated (equal to the number of target returns expected).

Values for K^{n-1}, B_M and 20 log B_M are given in TABLE E-3 for four values of K (0.9, 0.875, 0.85, 0.825). As mentioned previously the selection of a K factor should be dependent upon the number of pulses to be integrated. Based upon FAA radar characteristics,[15,16,17] Reference 13, and Equation E-1, the expected number of returns from a target is about 13 or 14. The K factors for FAA radars have been specified as 0.9 for ARSR-1 and 2 and as 0.875 for ARSR-3 (References 15, 16, 17). This gives a 20 log B_M of 17.5 and 16.4 dB for 13 and 14 target returns respectively.

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[15] *FAA Instruction Book, Air Route Surveillance Radar ARSR-1.*

[16] *FAA Instruction Book, Air Route Surveillance Radar ARSR-2.*

[17] FAA System Specification, FAA-E-2483, Air Route Surveillance Radar ARSR-3, 16 April 1974.

TABLE E-3

SIGNAL INTEGRATION FACTOR

Number Of Pulses Integrated n	Values of K^{n-1}, B_M, and 20 log B_M as a function of the number of pulses integrated and value of K											
	K = .9			K = .875			K = .85			K = .825		
	K^{n-1}	B_M^{n-1}	20 log B_M	K^{n-1}	B_M^{n-1}	20 log B_M	K^{n-1}	B_M^{n-1}	20 log B_M	K^{n-1}	B_M^{n-1}	20 log B_M
1	1	1	0	1	1	0	1	1	0	1	1	0
2	.9	1.9	5.575	.875	1.875	5.46	.85	1.85	5.34	.825	1.825	5.225
3	.81	2.71	8.66	.765	2.640	8.43	.722	2.572	8.2	.681	2.506	7.95
4	.73	3.44	10.73	.67	3.310	10.4	.614	3.186	10.06	.562	3.068	9.73
5	.657	4.097	12.25	.586	3.896	11.8	.522	3.708	11.4	.463	3.531	11
6	.591	4.688	13.4	.513	4.409	12.88	.444	4.152	12.36	.382	3.913	11.85
7	.532	5.218	14.35	.448	4.857	13.72	.377	4.529	13.12	.315	4.228	12.52
8	.479	5.697	15.11	.393	5.250	14.4	.321	4.850	13.71	.26	4.488	13.04
9	.431	6.128	15.75	.343	5.593	15	.273	5.123	14.2	.214	4.702	13.44
10	.381	6.516	16.3	.3	5.893	15.4	.232	5.355	14.57	.177	4.879	13.76
11	.35	6.866	16.73	.263	6.156	15.78	.197	5.552	14.89	.146	5.025	14.02
12	.315	7.181	17.12	.23	6.386	16.10	.167	5.719	15.15	.12	5.145	14.23
13	.283	7.464	17.46	.201	6.587	16.37	.142	5.861	15.36	.099	5.254	14.41
14	.255	7.719	17.75	.176	6.763	16.6	.121	5.982	15.53	—	—	—
15	.229	7.948	18.0	.154	6.917	16.8	.103	6.085	15.7	—	—	—
16	.206	8.154	18.22	.135	7.052	17	.087	6.172	15.8	—	—	—
[illegible]	.186	8.340	18.42	.118	7.270	17.23	—	—	—	—	—	—
18	.167	8.507	18.6	.103	7.373	17.35	—	—	—	—	—	—
19	.151	8.656	18.75	.09	7.382	17.36	—	—	—	—	—	—
20	.135	8.791	18.88	—	—	—	—	—	—	—	—	—
21	.122	8.931	19.00	—	—	—	—	—	—	—	—	—
22	.11	9.023	19.1	—	—	—	—	—	—	—	—	—
23	.099	9.122	19.2	—	—	—	—	—	—	—	—	—

Integrator Effect On Noise

In the section on radar noise, the statistical nature of the noise amplitude distribution was presented in TABLE E-1. TABLE E-1 represents the probability that a given noise level will be exceeded. The noise is described in terms of the parameter Ψo which is the mean square voltage in the IF prior to envelope detection by the video detector. Reference 14 provides a detailed treatment of the mathematical nature of the receiver noise. Marek[18] provides a detailed treatment of the action of the integrator on this noise. Only a qualitative description is presented here. In comparing the noise characteristics with and without the integrator, it will be more convenient to use the average of mean noise level as a reference rather than the mean squared voltage. In addition the standard term σ^2 (sigma) will replace the ψ(psi) used in Reference 14.

The noise in the IF is statistically described by a normal distribution with a mean of 0 and a standard deviation of σ. The effect of the envelope detection process is to convert this distribution to a Rayleigh distribution with a mean or average of $N = 1.2533\ \sigma$ and a standard deviation $\sigma_R = .655\ \sigma$. The distribution of $P\ (V_N)$, the probability that, after detection, the instantaneous noise voltage (V_N) lies between V and $V + dV$, is given by:

$$P\ (V_N) = \frac{V_N}{\sigma^2} \exp \left[- \frac{V_N{}^2}{2\sigma^2} \right] dV_N \qquad \text{(E-3)}$$

[18]Marek, F. L., *Video Integrator Model*, ECAC section Technical Memo, MD-60, July 1963.

The probability that a given threshold is exceeded is found by integrating Equation E-3 between the threshold voltage and infinity.

$$P(C) = \int_{CN}^{\infty} P(V_N)\, dV_N = e^{-.781C^2} \qquad \text{(E-4)}$$

where

$P(C)$ = probability that threshold CN is exceeded

C = ratio of threshold to average noise voltage

N = average noise voltage.

These are the values presented in TABLE E-1. This integration has been redone and the results given in TABLE E-4 for a threshold-to-noise ratio, C, based upon the average value of the Rayleigh distribution rather than σ (or Ψ) of the normal distribution. This is merely a change in the limits of the integration and does not affect the nature of the distribution.

The integrator sums or convolves the Rayleigh with itself continuously. The central limit theorem of probability states, in effect, that if a distribution is convolved with itself or other distributions enough times, a normal distribution is obtained with an average value and variance equal to, respectively, the sum of the individual average values and variances of the distributions convolved. Reference 18 validates this fact and determines a minimum value of B_M for which the relationship holds. It is established that if $B_M > 4$, the output of the integrator is described as a normal distribution with an average or mean of $N_2 = 1.253B\,\sigma$ and a standard deviation $\sigma_2 = .655\,\sqrt{B}\sigma$.

TABLE E-4

FALSE ALARM PROBABILITY OF NOISE DESCRIBED BY A RAYLEIGH DISTRIBUTION, P(c), VS. THRESHOLD-TO-AVERAGE NOISE VOLTAGE RATIO, C

Threshold-to-Average Noise Voltage Ratio C	Probability of False Alarm P(c)	Threshold-to-Average Noise Voltage Ratio C	Probability of False Alarm P(c)
1.0	.4559	2.7	3.26×10^{-3}
1.1	.3866	2.8	2.11×10^{-3}
1.2	.3227	2.9	1.35×10^{-3}
1.3	.2651	3.0	8.5×10^{-4}
1.4	.2145	3.1	5.27×10^{-4}
1.5	.1708	3.2	3.2×10^{-4}
1.6	.1339	3.3	1.9×10^{-4}
1.7	.1033	3.4	1.1×10^{-4}
1.8	.07849	3.5	6.6×10^{-5}
1.9	.0587	3.6	3.8×10^{-5}
2.0	.0432	3.7	2.1×10^{-5}
2.1	.0313	3.8	1.1×10^{-5}
2.2	.0223	3.9	6.4×10^{-6}
2.3	.0157	4.0	3.48×10^{-6}
2.4	.0108	4.1	1.8×10^{-6}
2.5	.00738	4.2	9.6×10^{-7}
2.6	.00494	4.3	4.9×10^{-7}

Since the integration of the noise is continuous, the value of the noise integration factor, B_∞, can be calculated from:

$$B_\infty = \sum_{n-1}^{\infty} K^{n-1} = \frac{1}{1-K}. \qquad \text{(E-5)}$$

Then, for the values of K used on TABLE E-3, the noise integration factor will be:

$$K = .9 \; ; \; B_\infty = 10$$
$$K = .875 \; ; \; B_\infty = 8.0$$
$$K = .85 \; ; \; B_\infty = 6.6$$
$$K = .825 \; ; \; B_\infty = 5.7.$$

Therefore for the values of K normally encountered in radar integrators the central limit theorem holds and the output noise is described by:

$$P\,(V_N - N_2) = \frac{1}{\sqrt{2\pi}\sigma_2} \exp\left[-\frac{(V_N - N_2)^2}{2\sigma_2{}^2}\right] dV_N \qquad \text{(E-6)}$$

where

$P\,(V_N - N_2)$ = probability that V lies between V_N and $V_N + dV_N$

$\sigma_2 = .653 \sqrt{B_\infty}\,\sigma$

$N_2 = 1.253\, B_\infty\, \sigma.$

The probability that a given threshold level is exceeded in the output of the integrator is determined by integrating Equation E-6 from the threshold level to infinity:

$$P(D) = \int_{DN_2}^{\infty} P(V_N - N_2)\, dV_N$$

$$= \tfrac{1}{2} - \phi\left[1.92\sqrt{B_\infty}\,(D-1)\right] \qquad \text{(E-7)}$$

where

D = ratio of the output threshold to average output noise voltage

$P(D)$ = probability that threshold DN_2 is exceeded

$\phi[\ ]$ = the integral of the normal probability density function between the limits of "0" and the value of the argument.

Values of P (D) vs D for the four values of K are presented in TABLE E-5.

Integrator Effect on Interference

If a string of interfering pulses with a pulse repetition frequency different from that of the desired signal is fed into the integrator, the recirculated interference pulses will not arrive back at the input to the integrator coincidentally with the next pulse in the interfering train and integration of successive pulses will not occur. However, for certain PRF's, partial integration can occur.

If the relationship in the following equation holds, partial integration will occur and the amount of integration can be determined:

$$r\,(PRF_{INT}) = s\,(PRF_{DSR}) \qquad \text{(E-8)}$$

TABLE E-5

PROBABILITY THAT NOISE EXCEEDS THE THRESHOLD LEVEL, P(D), AS A FUNCTION OF THE PARAMETERS K & D

D \ K	0.9	0.875	0.850	0.825
1.1	2.7×10^{-1}	2.9×10^{-1}	3.1×10^{-1}	3.2×10^{-1}
1.2	1.1×10^{-1}	1.4×10^{-1}	1.6×10^{-1}	1.8×10^{-1}
1.3	3.4×10^{-2}	5.2×10^{-2}	6.9×10^{-2}	8.4×10^{-2}
1.4	7.5×10^{-3}	1.5×10^{-2}	2.4×10^{-2}	3.4×10^{-2}
1.5	1.2×10^{-3}	3.3×10^{-3}	6.8×10^{-3}	1.1×10^{-2}
1.6	1.4×10^{-4}	5.6×10^{-4}	1.5×10^{-3}	3.0×10^{-3}
1.7	1.1×10^{-5}	7.2×10^{-5}	2.8×10^{-4}	6.7×10^{-4}
1.8	5.9×10^{-7}	7.1×10^{-6}	4.0×10^{-5}	1.23×10^{-4}
1.9	2.4×10^{-8}	5.0×10^{-7}	4.5×10^{-6}	1.9×10^{-5}
2.0	$< 10^{-9}$	2.8×10^{-8}	4.11×10^{-7}	2.3×10^{-6}
2.1	—	1.2×10^{-9}	3.0×10^{-8}	2.3×10^{-7}
2.2	—	$< 10^{-9}$	1.6×10^{-9}	1.9×10^{-8}
2.3	—	—	$< 10^{-9}$	1.3×10^{-9}
2.4	—	—	—	$< 10^{-9}$

where

PRF_{INT} = PRF of interfering radar

PRF_{DSR} = design PRF of receiver

r and s are integers.

The integer, r, indicates smallest number of times an interfering pulse must circulate through the integrator before it will coincide with another interference pulse.

A rather straight forward analysis (Reference 18) shows the dependency of the partial integration factor of interference, B_I, on the integer, r, given in Equation E-8. It is:

$$B_I = \sum_{n-1}^{\infty} K^{(n-1)\,r} \qquad \text{(E-9)}$$

It can be readily seen that if r, the number of times an interfering pulse must be recirculated before it will coincide with another interference pulse, is larger than the number of pulses that can be effectively integrated, M, the effects of interference is minimized since no integration occurs. TABLE E-6 gives values of B_I for various values of r and K.

In addition to the limiter normally found in the integrated video channels, most integrators and all of the FAA integrators are provided with their own input limiter. This device is usually adjustable and is set at a level relative to the integrator output threshold such that a single interference pulse will not appear at the output.

The actual setting of the limit level relative to noise covers a wide range in practice. Reference 16 specifies three different levels for the ARSR-3 (8, 10, and 15 dB above RMS noise). Instructions for ARSR-1 and -2 merely state that the limit level should be set at

TABLE E-6

PARTIAL INTEGRATION FACTOR FOR INTERFERENCE PULSES, (B_I), AS A FUNCTION OF THE PARAMETERS K & γ

γ \ K	0.9	0.875	0.850	0.825
1	10	8	6.66	5.71
2	5.26	4.26	3.6	3.13
3	3.69	3.02	2.6	2.28
4	2.9	2.4	2.09	1.86
5	2.44	2.05	1.79	1.60
6	2.13	1.8	1.6	1.46
7	1.916	1.60	1.47	1.35
8	1.75	1.52	1.37	——
9	1.6	1.42	——	——
10	1.53	——	——	——
11	1.45	——	——	——

the noise level. Skolnik[19] indicates a generally acceptable level to be 10 dB above noise.

The inter-relationship between integration factors, output threshold and input limit levels is given below:

$$\frac{L}{N}\,\frac{B_I}{B_\infty} = (D_{min} - 1) \qquad \text{(E-10)}$$

where

L = input limit level

B_I = integration factor from TABLE E-6

B_∞ = integration factor from the subsection on Integrator Effect on Noise

D_{min} = minimum output threshold level relative to $B_\infty N$, average output noise voltage, which will insure less than 100% probability of output due to interference.

The effect of a single pulse or a partially integrated pulse train that does not exceed the output threshold is to raise the average noise level for the duration of the output interference pulse. This in effect lowers the output threshold (Reference 18).

Using this new instantaneous threshold as the lower integration limit in Equation E-7, the probability of detecting an individual interference pulse can be determined.

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[19] Skolnik, M., *Radar Handbook*, Chapter 17, "MTI Radar," McGraw Hill Co., New York, NY, 1970.

For the case of interference at the input limiter level, L, there is an instantaneous output of average noise output plus the interference signal. The instantaneous threshold is given by the ratio of the quiescent threshold D over this interference output:

$$D_I = \frac{D B_\infty N}{B_\infty N + B_I L} \tag{E-11}$$

where

D_I = instantaneous threshold during interference.

The probability of detecting this output can be determined by using D_I in place of D in TABLE E-5.

While the evaluation of the integrator based upon false alarm rates and probability of detection is a good measure of its efficiency, it should be noted that the qualitative effect of an integrator on the nature of the interference is considerable, even for high false alarm rates. If the integrator is set up according to Equation E-10, then the interference will always appear as random noise spikes regardless of the absolute setting of D & L. Even if a high percentage of the incoming interference pulses cause a noise output, these outputs will not repeat from scan to scan and their ability to mask a target will be greatly reduced.

Example

The following example illustrates the calculation of the probability of displaying interference pulses from an uncorrelated source, i.e., a source with a PRF such that no interference pulses are integrated, $B_I = 1$. The following radar parameters are typical of radars found in the environment. First, the strength of the interfering signal is assumed to be at the input limit level, L. Second, the integrator

feed-back gain, K, is assumed to be 0.9. This corresponds to a noise integration factor, B_∞, of 10. The input limit level is assumed to be 8 dB above the average noise level:

$$L = N\ (\text{dB}) + 8\ \text{dB} = 2.5N\ (\text{Volts}). \qquad \text{(E-12)}$$

Finally, it is assumed that the radar gain setting is adjusted for a false alarm rate of 10^{-5}. This corresponds to a D of 1.7 that is obtained from extrapolating the data presented in TABLE E-5.

The instantaneous threshold (D_I) in the presence of an interference pulse, can be calculated by using Equation E-11:

$$D_I = \frac{DB_\infty N}{B_\infty N + B_I 2.5N} = \frac{1.7 \times 10}{10 + (1 \times 2.5)} = 1.36. \qquad \text{(E-13)}$$

This value of D_I corresponds to a probability of false alarm equal to 1.4×10^{-2} for the arrival of the initial pulse at the threshold detection (see TABLE E-5). Each additional time the interference pulse circulates around the loop, it is attenuated by 0.9. The cumulative probability of false alarm is equal to the sum of the probability for the initial pulse plus each of the repeat pulses. For this example, the cumulative probability is 4.3×10^{-2}.

If the radar gain setting was adjusted to yield a 10^{-6} false alarm, the probability of the interference pulse (s) exceeding the threshold is 7.9×10^{-3}.

APPENDIX F

DIGITIZER

The common digitizer (CD) is an FAA automatic radar detection system. This system statistically analyzes the output of the basic radar system, identifies targets, clutter and strobing, and creates a narrowband digital message that gives range, azimuth and nature of the return. This message is transmitted to a special computer that creates the radar display. The CD consists of two major components; the Radar Quantizer Group (RQG) and the Target Detection Group, (TDG). The RQG is an analog threshold device that converts all input signals to a standard response in amplitude and pulse width to be fed to the TDG. The threshold level is controlled by a manually adjustable DC bias and one of two automatic feed-back systems.

The TDG is actually a digital computer with a dynamic memory that is time synchronized to the radar transmissions. The output of the RQG is fed sequentially into each memory bit in time increments equivalent to 1/4 mile in radar range. This data is retained for a time period required for the antenna beam to sweep past a target.

During this time, the radar will have made N successive transmissions on N adjacent azimuths. The number N, which is M in APPENDIX E, is determined by Equation E-1 of the discussion on the delay line integrator and is a function of PRF, beamwidth, and rotation speed.

The computer memory is structured as a matrix that has N units wide (azimuth) and X units long (range):

$$X = \alpha R_{MAX} \tag{F-1}$$

where

$$R_{MAX} = \text{maximum radar range, in miles}$$

$$\alpha = 4 \text{ range blocks/mile.}$$

As the radar scans, the Nth previous azimuth block is erased in the memory and the new azimuth data added. Thus, the TDG has generated a "sliding window" such that for any given instant the data available for each range cell consists of the returns for the N previous transmissions.

The computer or TDG continuously reads out this matrix over smaller subwindows of varying dimensions in range and azimuth for the determination of the presence of a target, clutter or strobing.

The signals fed to the TDG by the RQG have a uniform amplitude and pulse width. The amplitude is normalized to one for convenience and the pulse width is equal to 1/8 of a range block. This latter value minimizes the possibility of a normal return appearing in more than one range block. The output of radar system is subjected to a threshold circuit. All targets, noise, interference, or combinations that exceed this voltage threshold and a minimum pulse width criterion will produce a standard pulse coincident with their leading edge. Input signals that are longer in duration than one range block will produce standard pulses in successive range blocks as long as the signal is present at the input to the RQG. The input threshold level is established in much the same way as the output threshold for the integrator of the basic radar (as discussed in the APPENDIX E). The value is set depending upon the false alarm rate and probability of detection required. In the FAA's common digitizer, there is a front panel adjustment for setting the median threshold level. This adjustment is calibrated in terms of percent noise. This is the ratio of the number of range blocks in which a standard pulse due to noise alone can be expected to the total number of range blocks.

A tremendous improvement is achieved in the use of the sliding window technique, an integration technique with a close analogy to the delay line feedback system. With the integrator, the output threshold is set so as to require X number of target returns to add before an output occurs. In the common digitizer, the "sliding window" memory matrix is filled with standard responses of a one (signal present) or a 0 (signal not present). The computer reads across the N memory cells for a given range and counts the number of ones present, as soon as a preset threshold is reached (T_L) the system declares a target leading edge to be present. As the sliding window shifts in azimuth, the computer continues to count the number of ones present in the N memory bits until the number drops below another preset threshold (T_T) at which time it declares the trailing edge of the same target to have occurred.

As an aid in interpreting the graphs that follow, a set of parameter values will be assumed for the further discussion.

These values are taken from the examples given in Reference 12 and closely approximate the median characteristics of the FAA's ARSR-2 radar as configured in the field.

1.	$N = 13$	Window size - number of azimuth elements in the memory matrix.
2.	$p_n = 0.05$	Percent noise, i.e., probability of noise producing a "1" in memory.
3.	$P_{fA} = 10^{-6}$	Probability of false alarm. Used to select T_L.
4.	$T_L = 7$	Number of returns in N memory bits in order to declare a target.
5.	$P_S =$	Probability of target pulse producing a "1" in memory dependent on p_n and signal strength, used to determine P_D.

6. P_D = Overall probability of detection of a target.

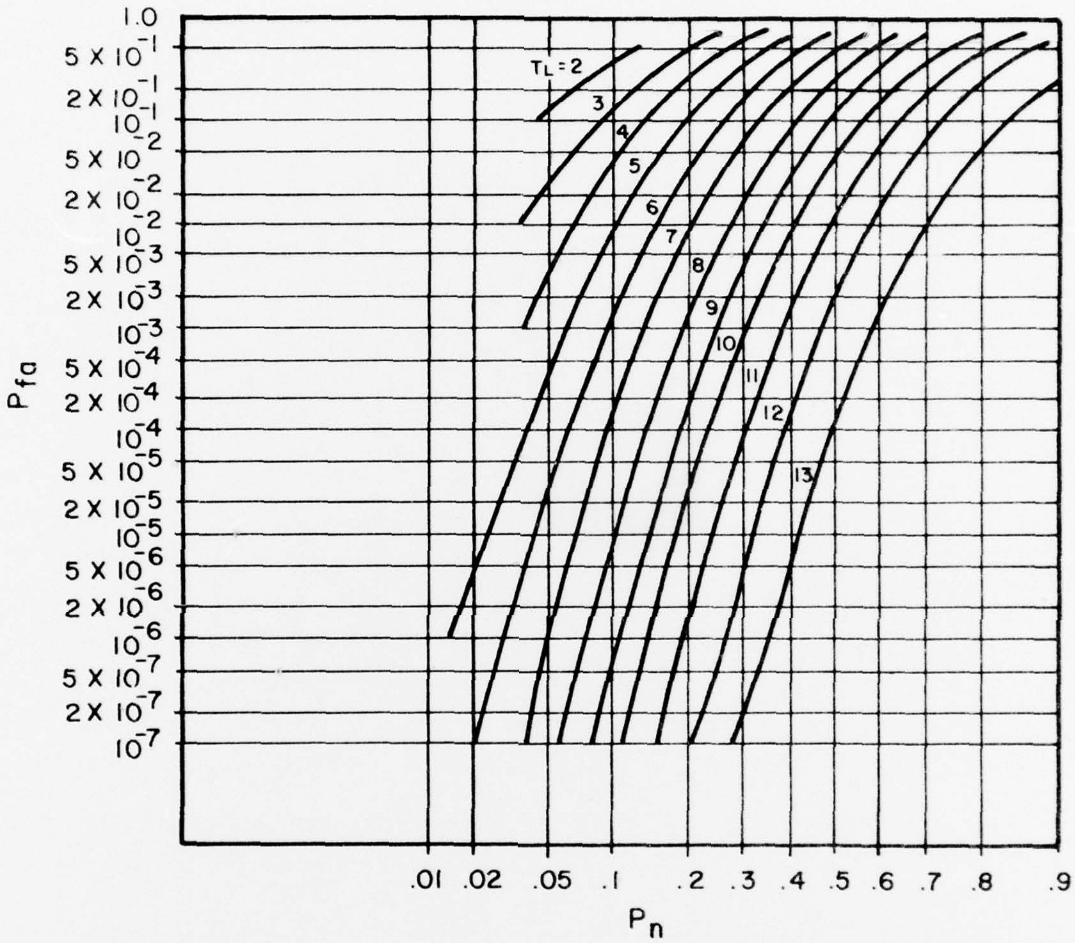
FIGURES F-1, F-2, and F-3 (Reference 12) typify the effectiveness of the sliding window detector using the parameters described above. These figures can be used to estimate the effects of interference.

For the parameters given, $P_n = 0.05$, $T_L = 7$, the false alarm rate of the system is 10^{-6}. For a radar with a 200-mile range and 1/4 mile range blocks there are 800 range blocks per scan or PRT. At 360 pps, the radar examines 288,000 range blocks per second. With a false alarm probability of 10^{-6}, only 0.288 false targets per second are expected.

For the initial consideration of interference, all feedback and variable threshold circuits will be ignored for the present. It is assumed that the interference is from a single source of a constant PRF and is capable of exceeding the input threshold continuously through the full 360° scan of the antenna.

The effect of the interference will be dependent upon the relative PRF's of the interference and the desired signal, as noted in the discussion of partial integration for the delay line integrator.

The relationship of the PRF's will determine the number of interference pulses that will be present in a range block N azimuth units wide. If the interference is capable of producing only one pulse in any 13-bit wide window, then the probability of it being declared a false target is then the probability that noise will produce the additional pulses required to exceed the threshold T_L. This in effect reduces the threshold T_L by the number of interference pulses present in the range window.



WINDOW SIZE = 13

T_L = LEADING EDGE THRESHOLD

P_{fa} = PROBABILITY OF DECLARING A FALSE TARGET.

P_n = PROBABILITY OF A HIT BEING DECLARED AT THE QUANTIZER OUTPUT DUE TO NOISE ALONE.

FIGURE F-1. P_{fa} AND P_n AS A FUNCTION OF T_L FOR A 13-BIT SLIDING WINDOW.

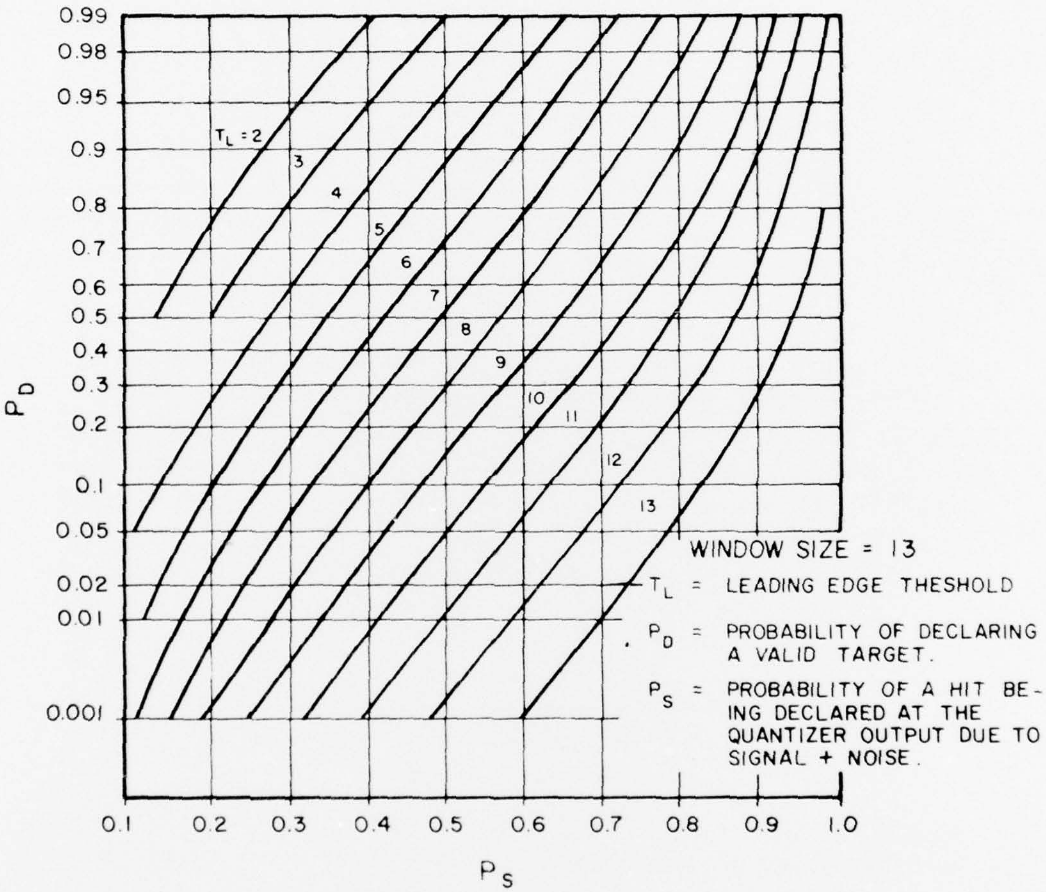


FIGURE F-2. P_D VERSUS P_S WITH VARIOUS VALUES OF T_L FOR A 13-BIT SLIDING WINDOW.

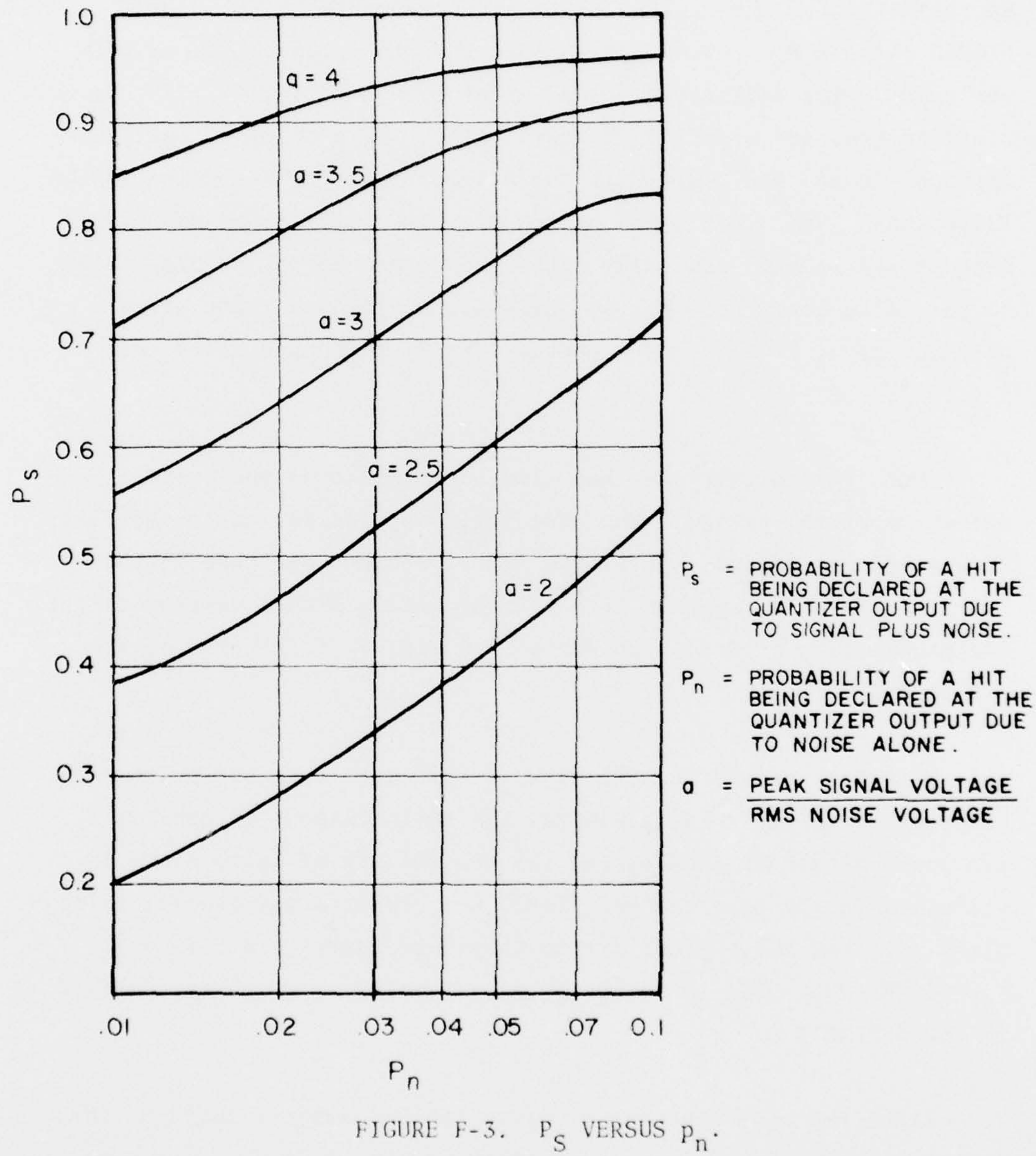


FIGURE F-3. P_S VERSUS p_n.

For the system under consideration here, T_L = 7 and the overall false alarm rate is 0.288 false targets per second. With one interference pulse present, the effective T_L would be reduced to 6. An approximation of the P_{FA} can be obtained from FIGURE F-1. From FIGURE F-1 and P_n of 0.05, it is seen that the probability of this one pulse being declared a false target is about 3×10^{-5}. Since this would be true for each interference pulse, the product of the interference PRF and the individual pulse probability of detection is the false alarm rate. For a PRF of 350 pps, this yields 0.0105 false targets per second, caused by interference and noise. Adding this to the false alarm rate due to noise alone yields a false alarm probability of 1.035×10^{-6}, whereas the P_n for noise alone was 1×10^{-6}.

Thus, the interference has almost no impact on the overall operation of the system. The same logic applies for the probability of detecting a target. In FIGURE F-2 it can be seen that if the interference pulse appears in a sliding window with a desired target, the probability of detection for a P_S = 0.5, T_L = 7, increases from 0.5 to 0.7.

When the interfering PRF is such that more than one pulse can be produced in the sliding window, the instantaneous thresholds T_L are correspondingly reduced and the probability of false alarm is estimated in the same manner. TABLE F-1 presents the overall false alarm rate for the typical system considered here, i.e., T_L = 7, P_n = 0.05, PRF = 360 in terms of the parameter r, which was derived in the APPENDIX E.

TABLE F-1 also contains a column labeled exact solution. This number was calculated from an equation presented in the next paragraph and is presented to demonstrate that the approximate solution is a useful value.

TABLE F-1

PROBABILITY OF FALSE ALARM (P_{fa}) DUE TO TEN INTERFERENCE SOURCES

Harmonic Number[a]	Pulses In Window	Effective T_L	P_{FA} Exact Solution	INT. Suppression	P_{FA} EST. FIGURE F-1
$r \geq 13$	1	6	1.01×10^{-6}	10^{-5}	1.03×10^{-6}
$13 > r \geq 7$	2	5	1.13×10^{-6}	10^{-4}	1.36×10^{-6}
$6 \geq r \geq 5$	3	4	2.2×10^{-6}	9.6×10^{-4}	4.6×10^{-6}
$r = 4$	4	3	1.04×10^{-5}	7.7×10^{-3}	2.[illegible] $\times 10^{-5}$
$r = 3$	5	2	6.52×10^{-5}	5.14×6^{-2}	1.2×10^{-4}
$r = 2$	6	1	3.22×10^{-4}	2.57×10^{-1}	6×10^{-4}
$r = 1$	13	0	7.2×10^{-4}	0	

[a] r is taken from; r PRF_{INT} = s PRF_{DES}, where r & s are integers.

MULTIPLE SOURCES

With multiple sources of interference, the suppression capability of the CD is still excellent. For the case where the PRF is chosen so that no single radar can produce more than one pulse in the sliding window, the probability of a false alarm in the presence of i sources of interference all producing signals above the threshold (RQV) can be computed from the following equations.

For $l < n$

$$P_{fa_l} < n = \sum_{i=o}^{l} \frac{i!}{l^m} C_i^m \; C_i^l \; \overline{DC}^{\,i} \left(1 - (l-i)\,\overline{DC}\right)^{m-i} \bullet$$

$$\sum_{j=n-i}^{m-i} C_j^{m-l} \; P_n^j \; (1 - P_n)^{(m-i)-j} \qquad \text{(F-1)}$$

For $l \geq n$

$$P_{fa_l} \geq n = \sum_{i=n}^{\max(l,m)} \frac{i!}{l^m} C_i^m \; C_i^l \; \overline{DC}^{\,i} \left(1 - (l-i)\,\overline{DC}\right)^{m-i}$$

$$+ \sum_{i=o}^{m-l} \sum_{j=n-i}^{m-i} \frac{i!}{l^m} C_i^m \; C_i^l \; \overline{DC}^{\,i} \left(1 - (l-i)\,\overline{DC}\right)^{m-i} \bullet$$

$$C_j^{m-l} \; P_n^j \; (1 - P_n)^{(m-i)-j} \qquad \text{(F-2)}$$

where

$$C_b^a \triangleq \frac{a!}{b!\,(a-b)!}$$

$i \triangleq$ integer 0 to l

$m \triangleq$ sliding window size

$n \triangleq$ threshold size T_L

$I \triangleq$ number at interference sources

$\overline{DC}^{\,i} \triangleq$ effective duty cycle of the interference sources

$$= \left[\sum_{i=1}^{I} PRF_i \right] \cdot \left[\sum_{i=1}^{I} \frac{PW_i}{I} \right]$$

$P_n \triangleq$ probability of noise producing a "1" in memory

$PRF_i \triangleq$ pulse repetition frequency for the ith interference source

$PW_i \triangleq$ pulse width for the ith interference source.

These probabilities have been evaluated for case of ten interference sources and the typical system values of $T_L = 7$, $r = 13$, $P_n = 0.05$ and average interfering pulse widths and PRF of 2 μs and 360 pps for an average duty cycle $\overline{DC} = 0.00072$.

The total probability of false alarm in the presence of this interference is $P_{FA} = 2.0 \times 10^{-6}$. This is equivalent to a false alarm rate of 0.3 per second or an interference suppression factor of 7×10^{-5}.

OTHER CIRCUITRY

Other circuitry in the CD that might react to radar interference is as follows:

SFL	Slow Feedback Loop
SE	Strobe Eliminator
FFL & ACE	Fast Feedback Loop and Automatic Clutter Eliminator.

The SFL is essentially a slow AGC and if affected, could cause desensitization and loss of targets. The SE essentially blanks the radar in the presence of continuous interference and jamming on a single azimuth. The FFL and ACE is a fast-acting, anticlutter logic circuit which raises the target thresholds in the presence of clutter. Interference could activate this circuitry and cause lost targets.

The slow feedback loop is designed to maintain a constant false alarm rate over a long time period by accounting for slow variations in the system noise level. It averages the system output over a two-second period and compares this to the preset voltage threshold level in the RQG. As discussed previously, this voltage is set to produce a certain percentage noise level in the CD. To accomplish this comparison, the CD counts the total number of unit pulses received over the two-second time period and compares this count to that which should be produced by the previously selected percent noise. The quantizer input threshold is then corrected accordingly. The nominal value for the preset threshold in terms of percent noise is about 5 percent. This is equivalent to stating that the expected number of unit pulses in the computer memory due to noise is 5 percent of the total number of memory cells. The percent noise value can be considered as an effective duty cycle for the noise. The introduction of pulse interference into the system in effect raises this duty cycle, i.e., the duty cycle of the interfering radar adds to the percent noise. Thus, a typical L-Band radar with a duty cycle less than 0.001 or 0.1 percent has little effect upon the total. The exact transfer function for translating the Δ percent noise into a Δ threshold is not known. However, if it is assumed that it is a continuous function that keeps the false alarm rate constant then a 1-percent increase (10 radars with DC = 0.001) in the total noise count would cause the system to raise the threshold to a level that would have produced 1-percent noise had the interference not been present. Examination of FIGURES F-2 and F-3 shows an almost imperceptible change in the probability of detection with such a change.

It is therefore concluded that multiple radar interference will not cause any desensitization due to action of the SFL.

The strobe eliminator logic in the CD requires a long string of successive ones in adjacent range bins before a strobe is declared. The radar interference will not produce such a signal and, therefore, will not activate the strobe circuitry.

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